3. POWER ELECTRONICS AND ELECTRICAL MACHINES TECHNOLOGIES

Advanced electric drive vehicles such as hybrid-electric vehicles, plug-in hybrid electric vehicles, fuel cell electric vehicles, and pure electric vehicles, 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 technology vehicles such as hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell hybrid electric vehicles (FCHEVs), and electric vehicles (EVs) 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. So, 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 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. In the pages that follow, the reviewer responses to each question for each project will be summarized: the multiple choice and numeric score questions will be presented in graph form for each project, and the expository text responses will be summarized in paragraph form for each question. A table presenting the average numeric score for each question for each project is presented below.

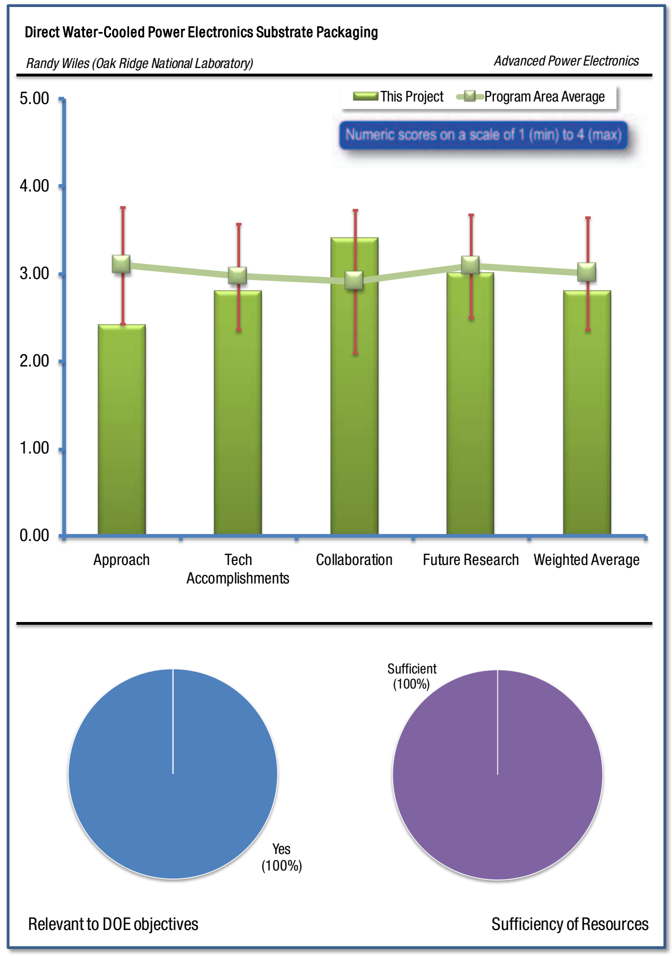
Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Direct Water-Cooled Power Electronics Substrate Packaging	Randy Wiles (Oak Ridge National Laboratory)	3-4	2.40	2.80	3.40	3.00	2.80
Inverter Using Current Source Topology	Gui-Jia Su (Oak Ridge National Laboratory)	3-7	2.83	2.83	2.83	2.83	2.83
High-Temperature, High-Voltage Fully Integrated Gate Driver Circuit	*Leon Tolbert (Oak Ridge National Laboratory)*	*3-9*	*3.50*	*3.33*	*2.50*	*3.17*	*3.25*
A Segmented Drive Inverter Topology with a Small DC Bus Capacitor	Gui-Jia Su (Oak Ridge National Laboratory)	3-11	2.33	2.83	2.50	3.00	2.69
Novel Flux Coupling Machine without Permanent Magnets	John Hsu (Oak Ridge National Laboratory)	3-13	3.00	2.67	1.50	3.00	2.65
Benchmarking of Competitive Technologies	Tim Burress (Oak Ridge National Laboratory)	3-16	3.50	3.75	3.25	3.50	3.59
Wide Bandgap Materials	Mahdu Chinthavali (Oak Ridge National Laboratory)	3-18	2.75	3.00	2.50	2.75	2.84
High Dielectric Constant Capacitors for Power Electronic Systems	*Uthamalingam Balachandran (Argonne National Laboratory)*	*3-21*	*3.00*	*3.00*	*3.50*	*3.00*	*3.06*
High Temperature Polymer Capacitor Dielectric Films	Shawn Dirk (Sandia National Laboratories)	3-23	3.67	3.00	4.00	3.67	3.38
Glass Dielectrics for DC Bus Capacitors	*Michael Lanagan (Pennsylvania State University)*	*3-25*	*3.00*	*2.50*	*2.50*	*3.00*	*2.69*

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Advanced Soft Switching Inverter for Reducing Switching and Power Losses	Jason Lai (Virginia Tech)	3-27	3.50	3.60	2.67	3.50	3.45
Development, Test and Demonstration of a Cost-Effective, Compact, Light-Weight, and Scalable High Temperature Inverter for HEVs, PHEVs, and FCVs	Ralph Taylor (Delphi Automotive)	3-29	3.40	2.60	3.60	2.80	2.95
Scalable, Low-Cost, High Performance IPM Motor for Hybrid Vehicles	Ayman El-Refaie (General Electric Global)	3-31	3.20	3.20	3.20	3.20	3.20
Advanced Integrated Electric Traction System	Greg Smith (General Motors)	3-33	3.50	3.00	3.67	3.50	3.27
Permanent Magnet Development for Automotive Traction Motors	Iver Anderson (Ames)	3-35	3.25	2.50	3.75	3.50	2.97
Power Electronic Thermal System Performance and Integration	Kevin Bennion (National Renewable Energy Laboratory)	3-37	3.33	3.00	2.67	2.67	3.00
Thermal Stress and Reliability for Advanced Power Electronics and Electric Machines	Michael O'Keefe (National Renewable Energy Laboratory)	3-39	3.33	3.00	3.33	3.33	3.17
Characterization and Development of Advanced Heat Transfer Technologies	Gilbert Moreno (National Renewable Energy Laboratory)	3-41	3.00	4.00	4.00	3.00	3.63
Air Cooling Technology for Power Electronic Thermal Control	*Jason Lustbader (National Renewable Energy Laboratory)*	*3-42*	*3.33*	*3.00*	*3.33*	*3.33*	*3.17*
A New Class of Switched Reluctance Motors without Permanent Magnets	*Tim Burress (Oak Ridge National Laboratory)*	*3-44*	*2.60*	*2.80*	*2.20*	*3.00*	*2.70*
Bi-directional dc-dc Converter	*Abas Goodarzi (U.S. Hybrid)*	*3-46*	*3.20*	*3.20*	*2.00*	*3.00*	*3.03*
Novel Packaging to Reduce Stray Inductance in Power Electronics	*Leon Tolbert (Oak Ridge National Laboratory)*	*3-48*	*3.50*	*3.00*	*3.00*	*3.00*	*3.13*
Power Device Packaging	*Fei Wang (Oak Ridge National Laboratory)*	*3-50*	*2.75*	*3.00*	*3.00*	*2.75*	*2.91*
High Power Density Integrated Traction Machine Drive	*Fei Wang (Oak Ridge National Laboratory)*	*3-52*	*2.60*	*3.00*	*2.40*	*3.20*	*2.85*
High-Temperature Air-Cooled Traction Drive Inverter Packaging	*Mahdu Chinthavali (Oak Ridge National Laboratory)*	*3-54*	*3.25*	*2.75*	*3.00*	*3.00*	*2.94*
Electro-thermal-mechanical Simulation and Reliability for Plug-in Vehicle Converters and Inverters	*Allen Hefner (NIST)*	*3-56*	*4.00*	*2.67*	*3.33*	*3.00*	*3.13*
Development of SiC Large Tapered Crystal Growth	*Philip Neudeck (NASA)*	*3-58*	*2.50*	*3.25*	*2.50*	*2.75*	*2.91*
Thermal Performance and Reliability of Bonded Interfaces	*Sreekant Narumanchi (National Renewable Energy Laboratory)*	*3-61*	*3.75*	*3.00*	*3.50*	*3.25*	*3.28*

Presentation Title	Principal Investigator and Organization	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
Thermal Management of PHEV / EV Charging Systems	*Kevin Bennion (National Renewable Energy Laboratory)*	*3-63*	*4.00*	*2.00*	*3.00*	*3.00*	*2.75*
Motor Thermal Management	*Kevin Bennion (National Renewable Energy Laboratory)*	*3-64*	*2.67*	*2.00*	*3.33*	*3.33*	*2.50*
High Performance Permanent Magnets for Advanced Motors	*Jinfang Liu (Electron Energy Corporation)*	*3-66*	*2.75*	*3.00*	*3.00*	*2.50*	*2.88*
Low Cost, High Temperature, High Ripple Current DC Bus Capacitors	*Ed Sawyer (SB Electronics)*	*3-68*	*3.00*	*4.00*	*3.00*	*3.00*	*3.50*
OVERALL AVERAGE			**3.10**	**2.97**	**2.91**	**3.09**	**3.01**

NOTE: Italics denote poster presentations.

Direct Water-Cooled Power Electronics Substrate Packaging: Randy Wiles (Oak Ridge National Laboratory)



Reviewer Sample Size

This project had a total of 5 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

One reviewer commented that temperature reduction is critical for power electronics and the power devices, adding that the approach is to reduce the cost while maintaining the performance. This reviewer was not clear on the module testing, but stated that this is a good approach that, if successful, will be a game changer. A second reviewer said this project supports the DOE goals for power density and cost. It is a novel packaging method that improves thermal efficiency and improves device reliability. A third comment was that the smaller, lower-cost power stages for inverters help to enable lower-cost inverters for electrified inverters.

Another reviewer mentioned the reduced size and weight, adding that this may reduce material/manufacturing cost, but that this is not clear yet. The final commenter said that this potentially reduces thermal resistance from chip to coolant, noting a possible volume and weight reduction. This reviewer felt it was questionable whether it reduces system volume or 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?

The first reviewer commented that this is a good approach and can reduce the weight and size of the cooling system. This reviewer added that more testing is needed on the system, as well as more information on cost reduction. Simulations were shown but the reviewer would need to see more testing to verify the performance of the design.

Another reviewer stated that this is a good novel approach to eliminating material layers and contacts, but there are issues with the geometric design. This may reduce cost and weight, but it is not clear how it is reducing the thermal resistance. This reviewer adds that uniformity of thermal resistance to different parts of the chip may be a major issue. If the thermal resistance to fluid is not uniform, it may accelerate the initiation of current nonuniformity and failure mechanisms. The lack of symmetry may also increase TCE mismatch stress. These issues could be evaluated using simulation. There are other ways to reduce thermal grease and thermal stack. The proposed method may result in a very thick ceramic and higher thermal resistance than other approaches. In the end, the chip area had to be increased to reduce thermal resistance. This defeats the whole purpose.

A third reviewer felt that this project is a novel idea, but may be more costly and have poorer performance than commercially available direct ceramic-cooled approaches, such as a direct liquid-cooled AlN chill plate. The results of this design should definitely be benchmarked/compared with existing products and other similar technologies published in the open literature. This comparison/benchmark should have already been done. The reviewer adds that the presenter did not appear to be aware of competing approaches and how this approach compared with them. If this approach does not yield a lower junction-to-coolant thermal resistance than existing approaches, further effort should be discontinued. This reviewer added that the assembly process (chip soldering, wirebonding, terminal attach, dielectric gel potting, etc.) will be difficult and probably expensive. This should be evaluated as a part of future efforts.

Another commenter felt that the concept to eliminate the heat sink and baseplate has merit in terms of thermal effectiveness. The conceptual model shown should function on the bench, but it needs more design work before it would be robust enough for automotive applications. The major drawbacks that this reviewer sees for this concept are: 1) sealing of the ceramic cylinders to the manifold under shock and vibration, 2) performing die attach and wire bonding using standard manufacturing equipment, 3) potentially large parasitic inductances since currents may have to travel around the cylinder, 4) large mass of the substrate, and 5) ineffective cooling due to small surface area of the coolant cavity. This reviewer added that other cooling technologies, such as indirect jet impingement (Danfoss Shower Power, for example), use submerged impingement jets to increase turbulence and surface area, and would be more thermally effective in addition to using standard planar substrates and manufacturing techniques.

One final reviewer stated that it is not clear how much silicon area is required to meet the group's junction temperature claims. Adding more silicon increases cost, and the reviewer asked that in the future the group please state the silicon area. Also, for the junction temperature claims, the group showed the power but not the current required for that junction temperature. Please state device current that creates the power losses. Also, this final commenter asked about the flow rate and pressure drop required for these junction temperatures.

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

The first reviewer said the project is on track for transitioning the new approach to sample and system demonstrations. Another reviewer stated that the program seems to be on schedule, adding that just assembling this mechanical configuration and obtaining experimental results is a significant achievement. It is important to calculate the overall thermal resistance from junction to liquid for each switch and each chip from the experimental results and compare/benchmark with other similar technologies as a go/no go criteria. A third reviewer added that progress has been good considering the novel technique and new processing steps. However, there is much more to be done to make this a commercial automotive product.

Another commenter stated that the team met the 13.4 kW/L target, which is good. This reviewer felt that it was not clear what the goals were for the design, adding that there were no calculations on the inductance for the buss. The team needs to conduct temperature cycling testing and evaluation, and should also conduct transient testing on the modules and in simulations.

A final reviewer stated that more work is required – thermal shock on the bonded ceramic, -40^{o}C to 175^{o}C. This reviewer added there are many internal seals in the inverter. How does the team address the long term possibilities of leaks? Over time and temperature, what is the expected degradation of the cooling channels? How is the bus bar attachment made to the power stage? Is there some strain relief between the bus bar and the power switch? Is there a plan to thermal cycle the power switch module with the bus bars attached?

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

The first reviewer said that there is a good team and set of partners working on the project. Another commented that the industry team members are good selections, adding the team really needs to keep a close eye on their plater. They are all problematic from time to time, since it is a process that is typically hard to control.

A third reviewer indicated that the team needs a good collaboration with simulation and reliability efforts for this new geometry and material configuration. A final reviewer believes that most of the work has been with subcontractors to resolve issues with die attach and wire bonding. This reviewer doesn't believe that other institutions are heavily involved.

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 offered a number of suggestions here. The first indicated the need to address some issues of buss structure and uniform temperature of the devices, adding that overall the plan is good and will address some of the technical barriers. Another reviewer said that the project's goal of producing a circuit demonstration is good, but it may be better to take a step back and perform simulations of temperature uniformity, thermal resistance, and to perform thermal cycling and thermal shock experiments on the new thermal stack even with dummy device samples, rather than moving forward with making full-up modules. A third reviewer offered the following recommendations: 1.Investigate using high-temperature plastics for the manifolds like those used in auto radiators. 2. Perform 3-D inductance analysis to determine parasitic. 3. Remove center mass and fill with non-porous material. 4. Determine how to coat substrates with soft-gel.

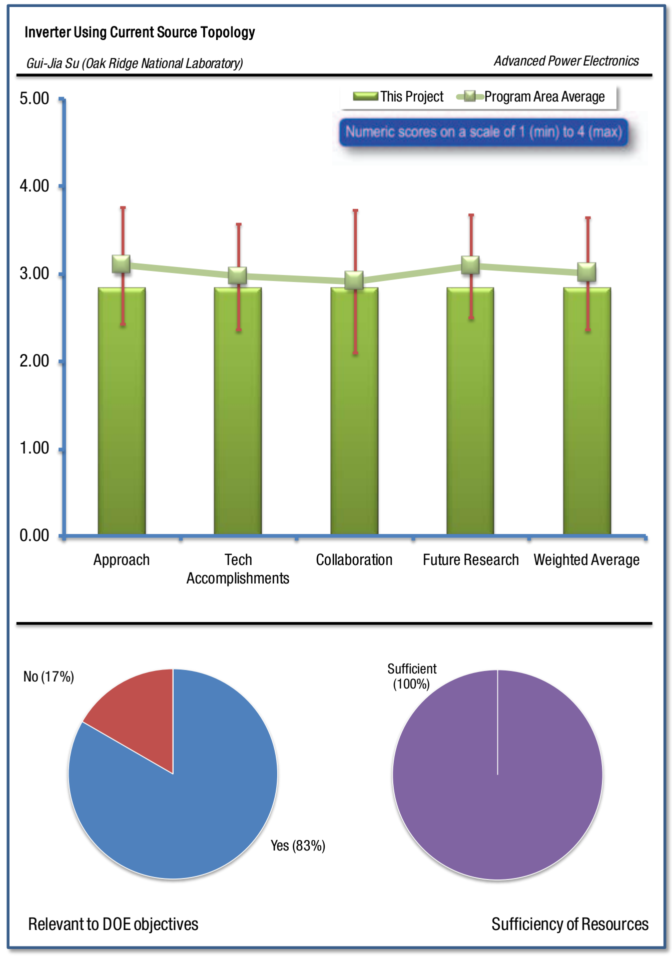
Another reviewer suggested that the team is approaching the immediate problems, but should also consider some of the longer-term potential problems. Will filtering be required for long-term performance of the coolant channels? Also, their junction temps over time will increase; do they expect to be under 175^{o}C at end of life for these junction temperatures? When they showed their power stage there was no controller; is there a plan to include the controller in their inverter package? What is the size of the finished inverter package?

A final reviewer stated that a comparison / benchmark of the experimental and simulated thermal results with other approaches must be completed as soon as possible, and a go/no-go decision made. If the performance is comparable / superior to other approaches, then this reviewer recommends that some reliability evaluations be conducted on: 1) ambient temperature cycling, and 2) thermal (power) cycling. The team also needs to look at actual temperature uniformity across each diode and IGBT chip experimentally and relate to long-term reliability. They need to assess effect of this octagonal geometry on overall system size, terminal/busbar placement, inductance, etc. and compare with existing designs. This reviewer added that the assembly process (chip soldering, wirebonding, terminal attach, dielectric gel potting, etc.) will be difficult and probably expensive. This should also be evaluated as a part of future efforts.

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

There were no comments for this aspect of the research.

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



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer stated that the reduction of cost and volume on electrical inverter are clearly defined as main objectives for PEV applications. Another stated this has the possibility of reducing capacitor requirements compared to voltage source converters, as well as voltage boost capability and battery charging. This also has potential of dual use as a charger. A third commenter felt that this is a very innovative topology study into ZCSI. It attempts to reduce ripple current and capacitor volume to meet DOE's goals. Another said the claim is to reduce size, weight and cost of inverter. This can enable the market for future inverters used in electric drive vehicles.

One reviewer stated that this can reduce the need for the DC bus capacitor, which will reduce the cost and weight. The capacitor is a big part of the volume of the power electronics system. For high temperature operation the size of the capacitor can increase significantly. The capacitor can be reduced but an inductor is added. The inductor performs better at high temperature than the capacitor. A final commenter stated that the project is hard to justify without showing better efficiency and fewer capacitors used in the circuit.

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 stated that this is a novel approach, and that teaming with MSU on topology design is effective. Using prior work on associated programs as a foundation is a plus. This reviewer added that it was difficult to assess the quality of the approach since actual circuit architecture was not discussed. Another reviewer commented that one of the issues of the current mode convert is the step-up voltage. The current mode converter is limited in step-up voltage; therefore, bi-directional operation is limited. The use of the quasi-Z network can help with the bi-directional operation. What is the size of the inductor? What is the operating frequency and is that frequency limited? This reviewer would like to see a study of the reliability of the system with the added parts.

A third reviewer said that the approach is inventive, as it explores a new topology space that combines a quasi-Z source and current-fed inverters. It does require reverse blocking IGBTs, which are not available right now. That may make this approach costly as these are new devices that are not widely available. It also requires an input inductor which adds cost and weight compared to a capacitor. This trade-off needs to be carefully weighed. The overall effect will be higher device and inductor losses compared to reduction of losses in the anti-parallel diodes. This reviewer recommends that efficiency be analyzed.

Another said that the claim is a smaller inverter by reducing the bulk x cap. Adding a trans-qZ network adds more component R, L's and C's. In their 10kW prototype picture, these extra components for the quasi-qZ network look large. What are the expected values and ratings of the components in the trans qZ network? This reviewer understands this is under patent review, but asked if some quantifiable information on size and weight could be shared.

A fifth commenter stated that there are apparently some issues with the current source inverter, so the Z-source is brought in to allow low speed, defeating the purpose. A final reviewer said the project efficiently addresses the major technical barriers but sometimes does not mention new issues coming from the new approach such as the reliability and cost of the three big contactors placed on the machine phases to switch from motor to charger (slide 7).

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

The first reviewer noted the improvement of the new current-fed Trans-ZSI, but added that there were only simulation results at this time. Another stated the need for more information on the trans-qZ network. A third commenter noted that a new qZSI was shown that can reduce the size of the inductors. This reviewer would like to see the waveform through the devices and inductors. What is the efficiency of this system and how does it compare to the capacitor system? Another commenter noted that they are currently they are in the analysis stage and it shows promising results. This reviewer thinks that the really big issues are ahead in developing hardware and controls. One reviewer stated that: (1) The circuit has fundamental issues. In the previous year's review, a "blank" block marked confidential was placed between the input and the CSI for the purpose of low-speed operation. This year, the block is changed, and a Z-source network is added. No explanation was provided to make a connection between this year's effort and last year's presentation. (2) No system performance and efficiency were presented. The presentation did not show distinctive features and results, rather staying at the same level as last year's qualitative comparison between VSI and CSI. It should show apple-to-apple comparison with solid numbers, not just qualitative explanation; that should not be the purpose of research. One final reviewer said that not much was presented for FY10 accomplishments, so it is difficult to determine if the program is on schedule and how well it is proceeding. This reviewer added that nothing was presented about inverter efficiency capability with this architecture. Reverse blocking IGBT/MOSFET switches are crucial to the future of this type of system. Series connections of IGBTs and blocking diodes will lead to lower efficiencies and increased power dissipation.

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

Comments were mixed in this section. The first reviewer stated that the team is made up of some of the leaders in the area and there is a good balance between industry and academia. Another added that this is an effective teaming arrangement with university and industry. A third reviewer said that the team uses MSU's early work as a baseline and all the protagonists seem to be involved in their respective field of expertise. This reviewer added that there was not a lot of material presented to judge this question. Another review noted some collaboration, but the group did not show clear linkage. One commentary suggested that the group possibly could use some collaboration with industry on power inductors and capacitors – can they be combined to reduce the packaging size? A final reviewer stated that they need the power module with reverse blocking IGBTs to be successful and convince others that this can be done.

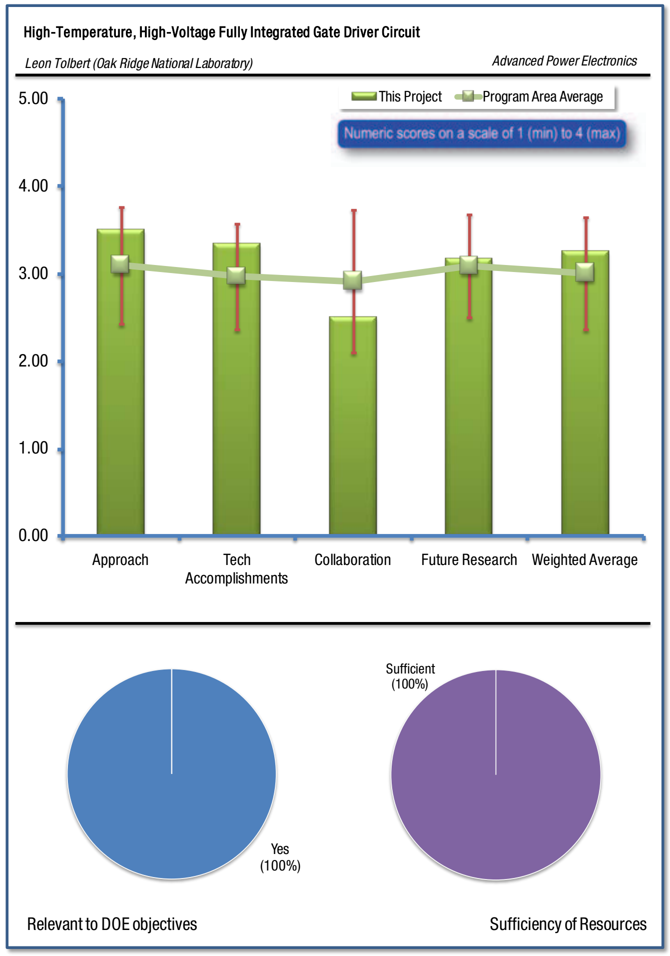
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Comments were mixed in this section. The first reviewer stated that there is a good plan for future work, while another stated that he or she thinks that the proposed technical work plan is well thought out and should be meaningful. A third reviewer felt that the research showed a good plan which included more design and simulation and construction of a 55 kW prototype system. This reviewer would like to see the voltage and current stress on the power devices. Another reviewed added that the team has a clear path but added that it was too early on in the program to fully appreciate the focus on barriers. One reviewer felt that not much result was presented. A final reviewer stated the logical next step is to build and test the inverter, but asked, why two? Are they different inverters or just in case one fails? (FY11 bullet)

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

There were no comments for this aspect of the research.

High-Temperature, High-Voltage Fully Integrated Gate Driver Circuit: Leon Tolbert (Oak Ridge National Laboratory)



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive. One reviewer noted that this is relevant for electric vehicles and possibly military applications, while another commented that the project enables and supports other projects that reduce size, weight, and cost by developing a high temperature gate drive to be used by other projects that supports the use of high temperature coolant. One person stated that, to the extent that a gate driver ASIC can assist the introduction of important power semiconductors based on wide bandgap materials, the answer is yes. Another reviewer added that the idea of building a gate driver for driving high currents at high temperature in SOI technology is a useful one for SiC and GaN based power electronics. This will greatly benefit the drilling operations where the electronics need to operate at temperatures exceeding 200°C.

One commenter said that in order to utilize high temperature power devices, high temperature gate drive circuits are needed. This project investigated the design of a gate drive circuit that can drive a SiC MOSFET or JFET. A final reviewer said that the integrated, high temperature gate drive is a critical aspect of the efforts to deploy and implement robust power electronic technology based on silicon carbide power devices. The ability to fully leverage the performance entitlement of silicon carbide power devices depends on the availability of driver technology with similar operating environment capabilities. The generic nature of the subject driver is also highly relevant to multiple switch technologies being developed.

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 generally positive in this section. The first reviewer stated that the PI's grasp of the technical nuances of the integrated circuit design and the target application are beyond question, while another indicated an excellent integration of analog and mixed signal expertise with power device subject matter experts resulting, in a highly relevant project with outstanding attributes. A third commenter stated that the approach of using BCD on SOI technology is a sound one. It leverages an existing technology platform while building on the strengths of the team in clever circuit design and access to wide band gap devices which can act as a test bed for the gate driver. Another reviewer said that the approach for the project is good. The use of the CMOS process with SOI is great and will allow for compact high-current gate drivers. This reviewer added that the approach of adding a protection circuit into the gate drive is good for protection of the power devices.

One reviewer stated that this is a development project with little novel research content, adding that it is beneficial, however, for ORNL to have a high temperature gate driver available to aid other projects. A final reviewer stated that the approach seems to have produced a viable design and good results. However, most power electronics systems use H-Bridge configurations with low-side and high-side switches. This gate driver would be enhanced by having drivers and the associated isolation for both the high-side and low-side switches. Although they may already have done so, it is recommended that the team canvass industrial power module users to determine features they value in gate drivers and incorporate them into this effort.

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

Comments were generally positive in this section. One reviewer stated that the gate driver appears to meet the objectives, while another added that the gate driver was tested on both a SiC MOS and a JFET device and was operated at temperatures up to 200^{o}C. A complete test chip was developed which showed that the devices can be constructed with a very small footprint. A third reviewer said that multiple iterations of the IC design have been accomplished, each one adding useful functionality while resolving limitations of earlier designs (often intentionally accepted as early spirals of an evolving design). This is great work. Another said that the integrated gate driver has already been successfully demonstrated which is capable of supplying 2.2 A at 200ºC (without any cooling mechanism) and a voltage up to 30 V. A next-generation driver is being designed which will add more features. The final commenter said that, with the exception of the lack of input isolation functionality, due to difficulty in identifying robust components, the project is considered to be highly successful.

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

Comments were mixed in this section. One reviewer stated that the very good coordination with power device manufacturers enabled accomplishment of a majority of the project milestones. Another commented that good collaboration and a good team were put together for development and testing. This reviewer added that they may need to add a SiC device manufacturer to the team. A third reviewer felt that the team may want to have other industrial users test the gate driver or review the results for more feedback.

One reviewer said that no evidence of any contribution by GM is seen in the presentation so far. A final reviewer commented that this project is focused, for collaboration, on technology support relationships, most obviously the foundry making the prototype IC chips. This reviewer added that it is unclear how much collaboration was forged with manufacturers in the wide bandgap semiconductor industry. However, at this late date in the project's life, it is probably a moot point.

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?

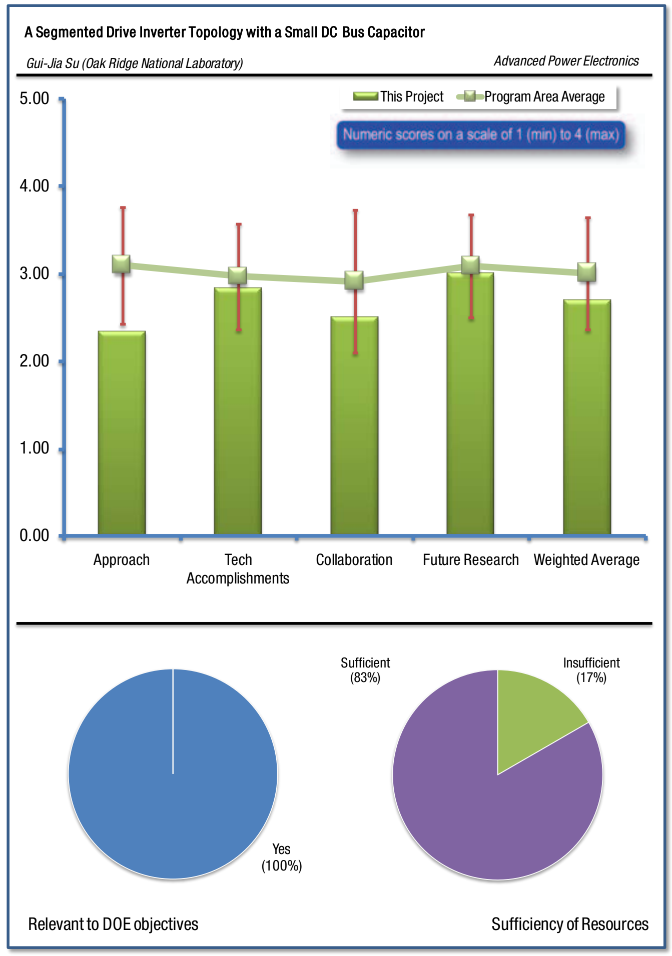
The first reviewer said that limitations of the developed technology are well-understood and viable solutions recommended, while another commented that the next generation of the gate driver will be completed and tested with SiC MOSFETs and JFETs. A third reviewer said that not much is left to do unless the project was extended with additional funding. The generation 5 chip might be worth funding by the DOE.

One reviewer stated that the team has plans for testing the new board in FY10. This reviewer added that no plans were stated for integrating the driver circuit into the power device package. The final commenter felt that no plan is evident as to how this technology actually gets commercialized or what the logical next step is.

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

No comments were provided for this section.

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



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said this approach can reduce the volume, weight and cost of the capacitor. This reviewer noted a reduction of cap ripple current by 60%, adding that this approach can increase the efficiency of the system. Another commenter said that reducing bus capacitance by 60% will be a valuable accomplishment, if indeed there is no other significant cost related to the new VSI technique used. A third reviewer noted that reduction of ripple current, motor current, lower costs, and inverter reliability benefits were covered in the presentation. Another commented that reducing the size of the bus caps can reduce the size and cost of the inverter, adding that the lower cost / smaller size inverter can enable electric drive vehicles.

One reviewer said that this project is aimed to reduce DC bus capacitance and meet the DOE goals for cost and volume. The final reviewer commented that the proposed technology involves modifying the standard drive topology and optimizing the PWM scheme to significantly reduce the ripple current flowing into the capacitor without additional silicon or passive (L or C) components, additional sensors, and control complexity. The reviewer added that this can substantially reduce the bus capacitance (at least 60%) and thus inverter volume and cost, and hence reduce the battery loss and improve battery operating conditions.

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 stated that the project involves simulation and prototyping, adding that it is feasible, while another found it hard to understand the speaker, which took away from the quality of the slides. Another reviewer said that there were not many details on the approach because of patent issues, adding that the simulation shows the reduction in the ripple current for this approach. A fourth reviewer said that, because the work is under patent review, it is not clear what changes would be required to implement this approach. This person asked, if silicon area is the same but the number of switches doubles, is there a twofold increase in gate drives? Also, how does the new control strategy affect throughput requirements?

One reviewer said that the process is fine with simulation, prototyping, and testing, but the reviewer did not see a lot of effort in terms of production intent. If the new technique will double the number of switches, even if the current rating will be lower, the increase in cost will be significant (which was not mentioned in the study). A better cost evaluation should be part of the approach to justify the study itself.

The final reviewer stated that the concept will reduce bus ripple and allow smaller input DC bus capacitance. The concept of phase interleaving is well known and has been applied in multi-section DC-DC converters. It has also been applied in various types of inverters such as multi-phase motor inverters, dual winding inverters and double ended inverters. Much of that work was done at GM for the past six years, including optimal control algorithms. For the proposed topology the additional set of switches, gate drivers, and motor windings adds a lot of complexity and cost to the inverter. Drawbacks include: 1. Six more drivers, 2. Six more switches, 3. Three more windings, 4. Three more motor cables, 5. Motor windings have to be wound with identical electrical characteristics, and 6. Ripple is non-zero for high and low modulation indices.

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

The first reviewer thought that the speaker slides were well done, while another commented that the simulation showed 60% reduction in current ripple, adding, if it is validated by experiment, then it will have importance. The prototype is underway. A third reviewer commented that results to date show that bus ripple can be reduced and the size of bus cap reduced by 60%. That shows a dramatic reduction in inverter volume. The work on optimizing PWM techniques is valuable. This reviewer recommends that the PI look at other topologies other than the dual winding motor that may have additional advantages. One such example is the open ended winding motor where each end is fed by a half-bridge. This has the advantage of full voltage rail utilization.

One reviewer would like to see more information about the control strategy, while another felt that a year to build 90% of a prototype seems long. This reviewer wondered if there may be some issue with resources or budget. The final commenter said that the team did not show many results on the technical accomplishment such as waveforms. Some simulation waveforms were given showing the motor current and the ripple current. A 28 % reduction was shown in simulation. Because the approach was not shown, it was not clear how the reduction in ripple current was achieved. The team needs to address the efficiency of the system.

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

The first reviewer did not see other institutions as a partner, while another added that no collaboration was presented. A third commenter stated that there was no collaboration at this time, but the team has plans to work with others on aspects such as packaging. Another reviewer said that collaboration was not mentioned that much. This person added that maybe talking about custom IGBT modules will help to recognize collaborative efforts. The final reviewer said that the prototype is done at ORNL. It might be beneficial if it can be collaborated with a motor company to expedite the prototype and testing process. It may also make sense to have academic participation to investigate the drawbacks of the proposed algorithm.

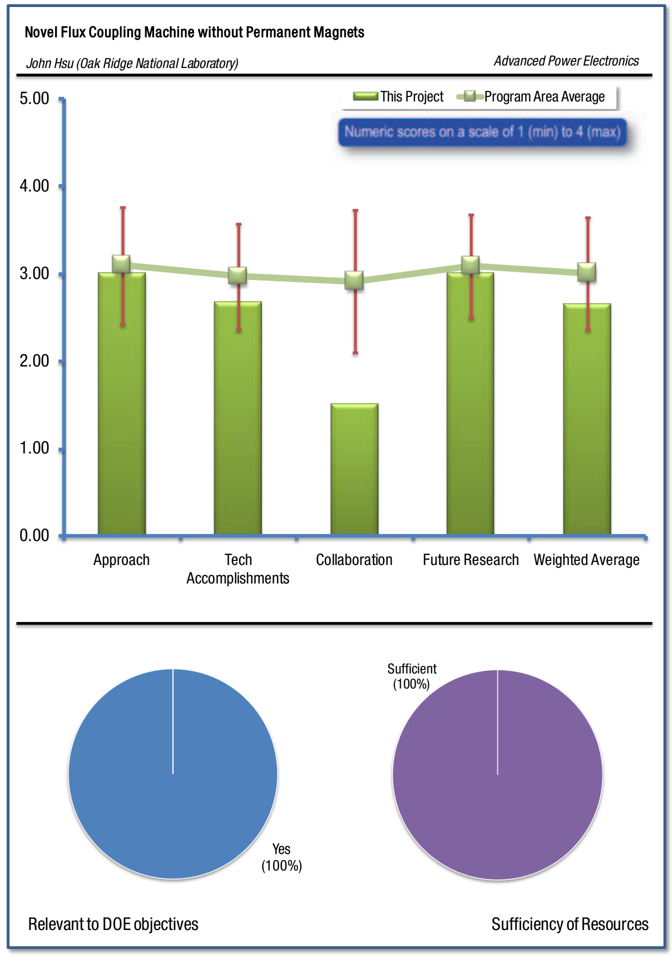
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Comments were mixed in this section. One reviewer said that either they do or should show a clear path to get to a 55kW system by the end of FY10. Another said that the future tasks are appropriate, adding that some advancement of the research objective is desirable. A third reviewer said that this is a logical way of proceeding but that this project appears to be behind. One final reviewer said the project has potential in the claims but needs more information. Noting the smaller cap but more switches, more gate drives, and more complexity for control, this reviewer said that it was hard at this time to quantify the benefit.

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

No comments were received on this question.

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



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer stated that reduction of permanent magnets can reduce the cost of the system and can reduce the motor size for high operating temperature, while another said this project aims to replace the permanent magnets found in electric motors, and added that this supports the DOE cost and power density goals for machines. A third reviewer said that by trying to eliminate the magnets, if successful, this approach will allow the achievement of a significant price reduction compared to actual PM machines used on EV and PHEV.

A fourth reviewer said electric traction motors are critical to the adoption of electric vehicles that displace petroleum. New topologies deserve to be explored through laboratories, especially ones that do not replace one dependency for another (this technology eliminates rare earth permanent magnets that presently create dependency on China). Another commenter said that, if successful in meeting the 2020 targets for the traction motor, this can be a key enabler in meeting the overall 2020 electric traction drivetrain targets. The final reviewer commented that the novel electric machine design concept addresses a major issue of today's electric machines, which is the high cost of permanent magnets. If the project is going to be successful, the novel electric machine design could potentially accelerate the implementation of electric drive systems in the automotive industry. This would support 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?

Comments in this section were mixed. One reviewer said a good approach was shown which utilized FEA modeling and design; the approach also investigated cooling of the system. Another stated that the approach is good but needs to move faster to building a prototype and verifying analytical predictions. Also, accurate efficiency predictions are needed. A third reviewer commented that the project is ambitious, possibly to a fault. For example, an externally excited machine that exhibits the novel flux path is sufficient without the exploration of novel stator winding. This reviewer added that what is most important is the need to assemble a proof of concept machine that can be used to refine the understanding of the machine before attempting optimization and folding in additional innovations.

Another commenter said the proposed novel electric machine design has a 3-dimensional magnetic flux path, which is different than in most of the electric machine concepts in use today. The researchers tried to avoid the very complex 3-dimensional modeling of design iterations because this takes a lot of time and computing power. But the real advantages of the novel machine concept can only be proven with full 3-dimensional FEA modeling. Additionally, this reviewer added, a new stator winding structure is proposed, which is independent from the general design concept of implementing a stationary field excitation for the rotor. The risk of this approach is that too many independent novel ideas are put into one project, and the differentiation between successful and unsuccessful ideas will be difficult. A fifth reviewer commented that there are several ideas expressed to achieve the objective (novel winding structure, field coil to eliminate magnet, hybrid cooling, field control optimized...), but at this time, there is no simulation or estimation of hybrid cooling and field control optimized. This reviewer asked if it is really necessary to have them for this machine.

The final reviewer stated that John Hsu is to be commended for a novel machine that has no permanent magnets and high power density. Separately excited motors and the wound field machine have been around for a while. But this motor is statically excited and has no slip rings. Because there is no rotating coil, it is capable of very high speeds. This reviewer also liked the ability to reduce field current at high speeds to improve efficiency. Drawbacks to this design are: 1. Complexity in the mechanical assembly, 2. High field losses, 3. No solution to mechanical stresses in the rotor, 4. Four air gaps, and 5. Double cooling.

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

The first reviewer said that a proof-of-concept, simplified motor is a better approach than attempted optimization at this stage of the program. This would accelerate the hardware build and allow for model calibration to create a second generation prototype that is more likely to fare well against DOE targets. Cost analysis should show more details about how the calculation was performed. In addition to material differences (additional iron and copper, elimination of magnets), manufacturing processes and tolerances need to be factored into cost calculations. With these factors, cost may become higher. A second reviewer said that, since the last time this project was reviewed, there has been a lot of effort to overcome some mechanical problems and to address rotor magnetic imbalance. However, there still remains an issue of high stress concentrations within the rotor at high speeds. Several attempts have been made without a solution. Another issue is the complexity of mechanical assembly and multiple airgaps.

A third reviewer said the team should show operation of speeds up to 1400 RPM, and added that comparisons of modeled results were compared to Camry with good results, but the weight was greater. The work did not meet the 2020 target. Does the research plan to address the weight issue? Another commenter said the simulation is encouraging, but questions concerning feasibility need to be answered by a prototype. It doesn't appear that anything was done on thermal and control this year. It was hard to judge the progress made. The increase in weight is understandable but is still a negative effect of the technique used. A fifth reviewer said significant progress has been made so far, but the researchers have to prove their claims with measurements of a prototype machine, which is already planned for the future. But it is necessary that detailed loss and efficiency simulations will be conducted before a prototype is available. The weakest point in the accomplishments so far is that no efficiency simulation results are available, e.g. eddy current losses in the solid steel core for the excitation field could be a big problem. Moreover, it has to be proven that the package volume claim is reasonable.

This final reviewer stated there is good progress but there are still several risks and questions to be answered. Also some of the assumptions need to be rechecked:

(1) The claim that this is a higher temperature machine is questionable since insulation is still a limiting factor.

(2) The novel winding method that can increase the fill factor by 50% is applicable also for PM machines.

(3) Efficiency maps especially along the rated power envelope should be evaluated.

(4) The assumptions for cost should be double checked. Do they also account for manufacturing cost or they are solely based on materials cost?

(5) Torque ripple results do not have enough resolution. The figure showing torque ripple over one mechanical cycles doesn't properly capture torque ripple/electrical cycle.

(6) It is not clear whether the design meets the 105^{o}C coolant inlet temperature requirement based on the proposed cooling scheme.

(7) Are the masses based on active mass or total mass?

(8) Detailed mechanical and rotor dynamics analysis should be performed to ensure the machine can be spun safely up to 14000 rpm.

(9) It would be beneficial to scale the design down to the 55 kW to check if there are any issues with scalability as well as provide better comparison with the 2020 specs.

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

One reviewer said no collaboration is seen at the moment, and another said no industry or laboratory partners are shown at this time. A third reviewer added, as already mentioned in the presentation, there is no sponsor for this project. Involvement of an industrial partner is needed. Another reviewer said there are no collaborations at the moment, as this is a pure research project in an early stage. This reviewer added that a bigger interest from the industry will be there, if a successful prototype testing has been conducted.

Another commenter believed most of this work is being done at ORNL internally, and added that perhaps some better collaboration could be made with a university that specializes in electric motors. One final reviewer said there is little collaboration within this project, which hopefully will change if the prototype motor shows promise. It is important for the electromagnetic and mechanical engineers and designers to work closely before building the first unit, and it is also important to consider the controller that will be used to drive the motor and to have their involvement. It is not clear that ORNL internal collaboration is sufficient.

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?

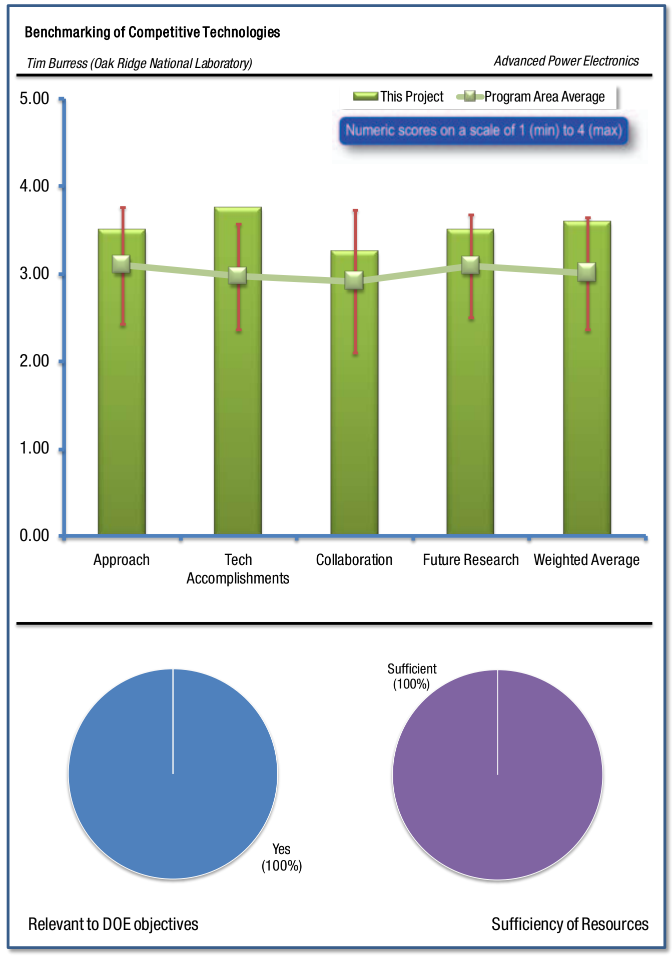
The first reviewer said building the prototype and experimentally verifying the analytical results is a critical step. Another commented that the future work plan is generally good. As mentioned above, more detailed simulation work has to be done to prove some of the claims before a prototype is available. A third reviewer said proving the concept through experimentation is the logical next step. This reviewer is curious to see results from the prototype and is sure that it is the case of eventual partners.

Another reviewer said the team needs to address the issues of going from simulation to prototype. The team also needs to investigate the losses with this design. A fifth reviewer commented that risk mitigation is not a strong point with this program. It is an ambitious program that should consider pathways to reduce the complexity of the prototype. Assuming that suggestions from past and present reviewers are heeded, this reviewer looks forward to the prototype results. The final reviewer recommended trying to cast the Zip Lock fasteners using aluminum much like the rotor bars in an induction motor. This will eliminate complex machining, and precision assembly.

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

No comments were received for this section.

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



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said that, by analyzing what is done in this arena, this study gives a good understanding of the state-of-the-art and constitutes a good knowledge base to build upon. A second commenter said the comparison has good reference value. The industry and research organizations have a basis for comparing their target system performance. The way that Toyota designed their power electronics can be the initial reference to some design teams. A third reviewer said that benchmarking electrification technologies that are now commercialized will help others incorporate "lessons learned" through the careful evaluation of those technologies. It will help those who are not as far along to catch up and speed the commercialization of new systems, and hence, vehicles that displace petroleum. The final reviewer said it is very important to understand the marketplace for power electronics, and added that this benchmarking activity attempts to understand recent technology.

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 really liked this intelligent approach, and added the team was doing an excellent job. Another said the research team did a good job to understand how Toyota designed the system when they took the components apart. There was a very good explanation for what they found. Further improvement is possible by injecting design expert in the field, so the design philosophy can be explained better. This is apparently beyond the current research team capability, but it would be good to incorporate more design experts who can provide more insight to the design philosophy.

A third reviewer said the approach is to do a detailed tear-down of Toyota hybrid electronics and motors. These are considered the benchmark standard today. The final reviewer said expansion of the work to evaluate the communications system, signal processing, and approach to achieve compliance with standards would be useful. For example, is dual processing used to ensure that undesired torque is not produced? Materials evaluation (lamination steel, magnets, aluminum grade, potting compounds, PC board layers, processor selection, etc.) would also be worthwhile. Some of this may already be in the detailed reports. Improvements to the power electronics, machine, and cooling technologies are evaluated well through this effort.

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

Comments were generally positive in this section. The first reviewer said the team has provided very detailed results of the production system, and added that they took pictures and explained how each component works. A second reviewer said the work is timely and relevant. Work on used systems (160,000 miles) was good to see and should continue whenever possible. Following observations with confirmed or educated guesses as to reasons should continue. Another commenter said that, so far, the results are very enlightening to see how much progress is being made. It shows some dramatic reduction in wires and heat sinks. The final reviewer said there was excellent analysis of the 2010 Prius, and pertinent comparison with previous models for the drive and motor.

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

The first reviewer said this work is being done in connection with other DOE participants, while another noted that there are numerous collaborators that are doing their part of the job, along with good management from ORNL. A third reviewer said generally collaboration is good, and added that more power electronics and motor design experts can be brought in to further exploit design philosophy. The final reviewer said collaborating with manufacturers would also be appropriate, especially to help answer and document the deduced reasons for the design choices observed.

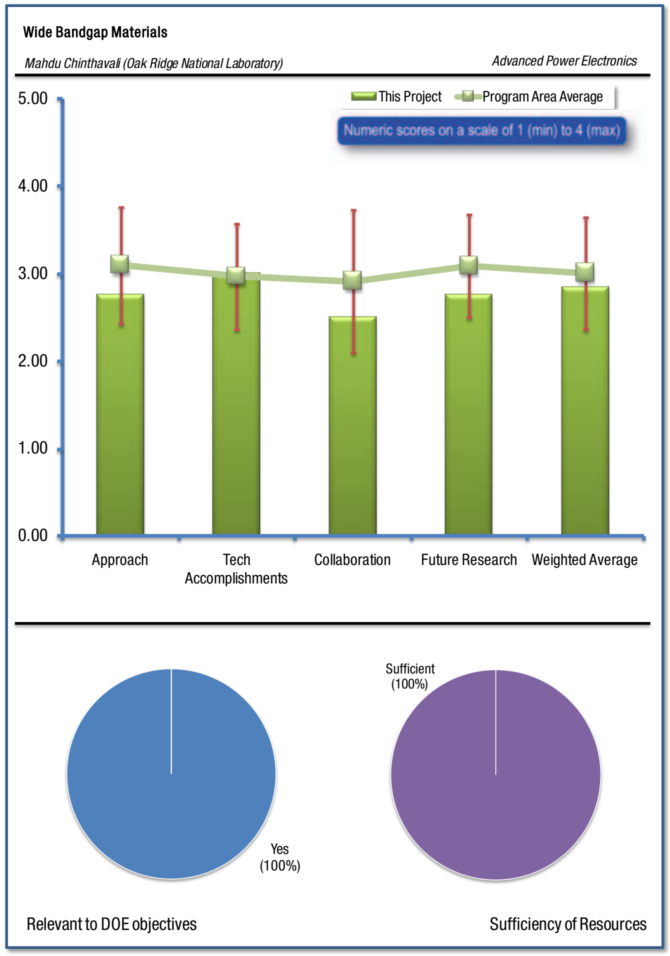
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said this project seems to have reached its end of life as defined and hopes that some decision to continue it will be taken in September. This project is valuable for the EV/PHEV community as a knowledge database. It will be valuable to extend the study to emerging vehicles. Another stated that, although there is a comment from the audience about evaluating the U.S. manufacturer's design, the team has done an excellent job so far and should keep on doing the good work. The final reviewer said to see comments above for suggestions on future research to dig more into the details that will help U.S. manufacturers close the gap with foreign manufacturers. Evaluation of the controller and driver boards to a deeper level would be useful future work.

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

No comments were received for this aspect of the research.

Wide Bandgap Materials: Mahdu Chinthavali (Oak Ridge National Laboratory)



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said this work is extremely relevant to the mission of DOE for petroleum displacement or at least petroleum reduction. The main objective is to evaluate the use of wide band gap devices such as SiC or GaN diodes and FETs in hybrid and electric vehicles. It is anticipated that the inverter efficiency can be increased, thereby improving gas mileage and reducing cooling infrastructure by use of wide band gap devices in the boost and inverter sections. Another reviewer commented that most automotive OEMs have active R&D efforts to increase efficiency and thermal flexibility in EV power electronics using emerging commercially available SiC power semiconductor devices (FETs and Schottky diodes). This reviewer added that it is recognized throughout the HEV/PHEV/BEV industry that wide bandgap semiconductor technology is relevant to future petroleum displacement through consumer adoption of HEV/PHEV/BEV. A third reviewer said high temperature devices offer the promise of eliminating a coolant loop and/or using higher current densities. This may reduce weight and size in the future, leading to fuel economy savings. However, cost is the barrier at this point. The characterization/modeling/system impact work is important to track progress.

The final reviewer said the performance entitlement of the wide bandgap class of semiconductor materials has been demonstrated to be capable of significant power conditioning and distribution equipment efficiency advantages over state-of-the-art Si power device technology. The subject project is appropriately quantitatively evaluating the device performance characteristics to validate the terminal performance characteristics to assess technology maturity and suitability for system utilization. In addition, the development of SPICE models for the evaluated device technologies is a necessary thrust to enhance and accelerate implementation of these technologies by making available applications engineering design tools.

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 in this section were mixed. The first reviewer said the overall goals are good: characterization, modeling, and system simulation to benchmark and monitor progress of wide bandgap device development and potential impact on EV. A second reviewer suggested they consider including power dissipation curves for use in determining forward SOA space evaluation/determination. This reviewer added that implementation of a single package for comparison and benchmarking would also be appropriate for this and other characterizations in order to evaluate the differing switch technologies. Very good project structure and execution was also observed. Efforts were made to evaluate and characterize gate drive response needs when considering threshold voltage shifts with increasing temperatures (especially for e-JFETs).

A third reviewer stated that the approach is seriously flawed. Obtaining devices from vendors and measuring dc and dynamic characteristics and building models is simply duplication of the data already being provided by the vendors. Minimizing thermal impedance is attacking the wrong problem because the losses with wide band gap devices are already lower. Minimizing inductance is useful but it is at the level of module design where the PI has no experience. A better approach would be to design an inverter using commercially available wide band gap modules, increase the switching frequency in the boost section to reduce the size of the reactor and reduce the size of the cold plate and number of silicon IGBTs in the inverter section. This should be done just for wide band gap diodes as a first step. Benchmarking should be done with all silicon modules.

The final reviewer commented that, clearly, as this project has progressed, the team has dramatically improved their familiarity with the technology, and their evaluation of the technology is approaching the quality of the manufacturers of the devices themselves. The comment made by the presenter in response to the question about characterizing gate energy, etc., to the effect that creating a data sheet is not the goal of the project is a welcome reflection on the true contribution that this project can realistically make. In that spirit, this reviewer encourages the presenter in the future to take care when making comments about the true rating of devices. The reviewer knows and agrees with the presenter's intended technical context, and also knows that taking care in the choice of words will avoid the possibility of confusing the audience. The future work involves creating behavioral models and making system relevant conclusions about the technology. This final reviewer commends the project team for this choice, which is a good use of the team's expertise and better reflects the needs of the community for understanding the value proposition that wide band gap semiconductors might have in a very cost sensitive industry.

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

Comments in this section were mixed. The first reviewer said good progress has been made in developing and obtaining equipment for basic tests and in performing basic characterization of a number of samples from different sources. Another commented that the static evaluation of devices appears to be essentially complete and to be largely done well. Dynamic evaluation was not reported as that work is still in progress (gate driver board “sent off”). The behavioral modeling effort appears to be embryonic, as no progress was reported. A third reviewer said that validation of SPICE models in relevant topologies would be appropriate and a good subtask to accomplish to compare to inverter topology being planned. The final reviewer said that, assuming the project has been ongoing since October 2001, the progress is extremely slow. This reviewer noted that there is no detailed calculation of higher efficiency of an inverter based on wide band gap devices, despite the fact that these devices have been available for a number of years.

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

The first reviewer noted the inclusion of GE (MOSFETs), United Silicon Carbide (BJT), and Northrop Grumman (JFET including cascades), while a second reviewer said the project has identified sources and obtained samples from a number of sources. However, this reviewer added, coordination with other labs that do SiC/GaN device testing and modeling seems to be lacking. Another reviewer said there is poor evidence of any collaboration with the partners. The devices that have been measured are not state of the art, no significant effort has been made to acquire recent devices, and the testing could have been easily done at the University of Tennessee-Knoxville, whereas ORNL could have focused on building an inverter. The final reviewer said it is unclear how much this project collaborates with the applications engineering support of the wide bandgap vendors. This reviewer’s guess is very little, which could be improved. University of Tennessee may or may not be the best choice for behavioral modeling of wide bandgap semiconductor devices. Other academic institutions are further along in that technical area. This final reviewer asks whether the team reached out to any of these institutions.

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?

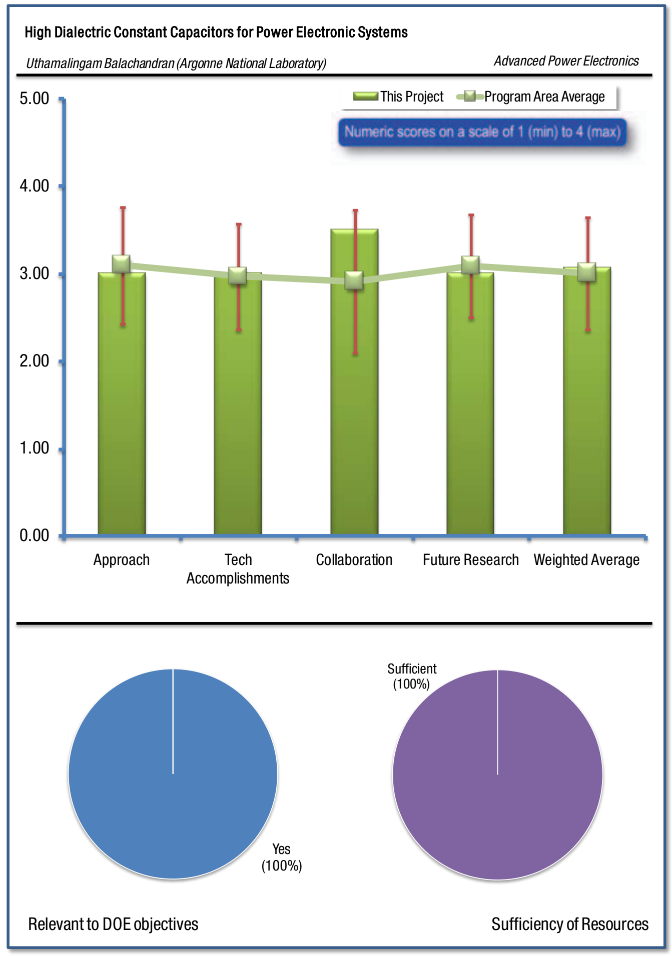
The first reviewer said reasonable objectives seem to be set for future research. Again, risk might be reduced by improving the collaborations. But the future research is clearly aimed at the most valuable contribution that this project can make, which is helping to answer the question “Do wide bandgap semiconductors have a value proposition in the automotive industry?” Another reviewer said completing the design of an air-cooled inverter is a good goal, and added that an even a better goal should be to build and test the inverter. Simulations are useless in such applications. A third commenter suggested the team might consider evolving this project or a follow-on activity to include a packaged (multi-chip type module packages) wide band gap technology assessment.

The final reviewer stated that this project would be more effective if it produced a comprehensive list of tests needed for evaluation of devices. Similarly, a comprehensive list of device performance metrics that can be used to evaluate device suitability for vehicle applications would be beneficial. Some theoretical analysis of how the characterized device performance would impact inverter performance should be provided and updated as the device technology evolves. Near-term suggested changes to the evaluation procedure include addition of basic measurement methods like gate and gate-drain charge. Also, each device should be given an independently derived current rating based on watts/cm^2, package thermal resistance, and SOA modes. Reliability and qualification tests: HTOL, HTRB, HTGB are difficult long term measurements and may be beyond the scope of the work. However, it may be appropriate to perform specific reliability tests for known SiC/GaN device specific concerns (for example, forward bias degradation and gate voltage drift). This final reviewer added that more comprehensive device characterization will be needed before accurate modeling and simulation results can be obtained.

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

No comments were received for this question.

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



REVIEWER SAMPLE SIZE

This project had a total of 2 reviewers.

QUESTION 1: DOES THIS PROJECT SUPPORT THE OVERALL DOE OBJECTIVE OF PETROLEUM DISPLACEMENT? WHY OR WHY NOT?

The first reviewer felt this project did support the overall DOE objectives of petroleum displacement based on the research and findings presented. The other said the project proposes to reduce the size of vehicle inverters by ultimately incorporating the DC link capacitor function within a printed circuit board. While there are several challenges that need to be addressed, this work is worthy, as it is a different approach to solving the problem compared with traditional wound film or electrochemical capacitors used for this application.

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 lone commenter stated that technical barriers should be carefully worked out with the direct customer for the capacitor technology the team is working toward: the inverter design engineer. For example, the capacitance measured by a bridge with zero bias is meaningless for the intended application. The capacitance while biased at the DC bus voltage is what is important: dQ/dV at 450V for the target application. Presented results should relate to that condition, not at zero bias. The graceful failure mode is critical to the viability of this technology, especially as fabricated in a multilayer device.

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

The lone commenter said the increased size of capacitor elements and the improved breakdown strength were positive signs. This reviewer suggests that dielectric withstand be reported in volts/micron, which is more typical of how dielectric strength is measured in the capacitor industry. Clear reporting of results is necessary in conditions relative to the application, such as leakage. What is the leakage per µF at a given dielectric stress? This is more relevant than leakage/cm^2 with no voltage stress indicated.

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

The first reviewer said very good collaboration on this project was demonstrated. The other reviewer said one area that was not addressed was the method used to connect the stacked layers in parallel. This reviewer does not know if a separate institution would have value in this regard: possibly a leading edge PCB manufacturer would be able to assist for that planned implementation. For discrete multilayer capacitors, would talking to a manufacturer of multilayer ceramic capacitors add any value there, or has Sandia National Labs a state-of-the-art expertise?

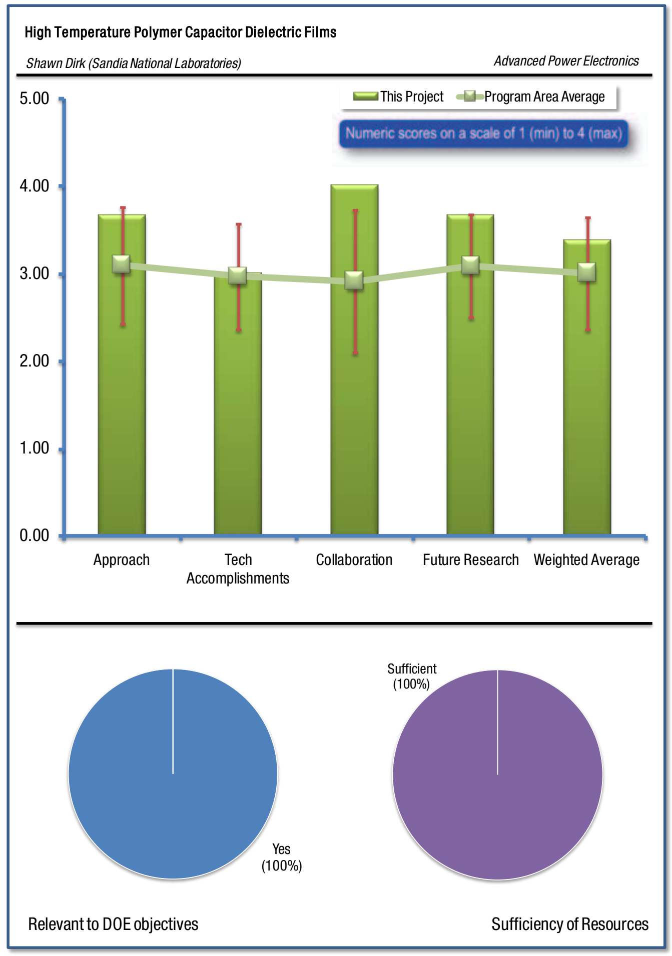
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The lone commenter said that for such high DC link capacitor currents (100ARMS), interconnect such that active electrodes are able to share this current will be a non-trivial portion of the technical development. This reviewer did not see any planned activity in this area for future work. This current has significant magnetic interaction implications that can cause unexpected heating. For example, the current through a stacked film capacitor will cause a magnetic field that will have components perpendicular to the electrodes, generating eddy currents. These have been shown to be non-trivial effects. As the capacitor volume is made smaller (enabled by high K materials) current density uniformity and magnetic effects become more important.

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer commented that the high-temperature polymer capacitor dielectric films are needed in the industry if they can be produced in volume and at competitive pricing. Another commenter said the higher temperature smaller capacitors can make an inverter smaller. However, solvent casting is not a low cost process. This reviewer indicated a need to move to an extrusion process as suggested in the team's presentation.

The final reviewer said that one important attribute of this research is that low-cost polymers are being studied. If cost is not comparable to the current polypropylene solution, it has little hope of being adopted. The goal of a cent and a half/µF appears to this reviewer to be a "pipe dream." It would require a break-through in capacitor technology far more significant than a new capacitor film, but the reviewer adds that that is not to be construed as a criticism of this work, and is more of a comment on an unrealistic goal set by DOE.

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 thought the speaker did a very good job in presenting the information and the research was excellent. This reviewer's experience in the field questions the high heat capability, and is concerned that the costs will be high due to being a specialty film in low volume. Another reviewer said that the work needs to move to an extrusion process, with thinner films and higher breakdown voltage. Also, will this material be comparable with the existing metalization processes for PP, or is more invention required?

The final reviewer stated that a well-focused effort is seen here, with what appear to be relevant players. This reviewer expects to see more "capacitor results data" in the future. This reviewer was not qualified to comment on the organic chemistry aspects of this work, although the reviewer can appreciate the difficulties in going from "the lab" to "a pair of film rolls from which capacitors can be manufactured." It is one of the biggest barriers for a "new film." The ECI connection is a "natural." This reviewer continues to encourage characterization of self healing capability relative to the 450V DC bus requirement and the dielectric stress level one would expect to use for that application.

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

The first reviewer said this was a great technical concept, but needed to see more quantified data to verify progress and product availability as well as true costs. This will be an excellent technical project if desired results can be achieved for market and product use. A second reviewer commented that the team needs to show the finished capacitor size, weight, and projected cost. Does it meet the capacitor targets? The final reviewer said it was encouraging to see more interaction with ECI. Several problems were solved. This reviewer had the following questions: for the higher K formulations, does capacitance change with applied voltage? (dQ/dV at the applied bias V/µm, should be referred to DOE target 450V bus voltage.) Have any leakage tests been made relative to the above target voltage and temperature stress?

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

Comments were generally positive in this section. The first reviewer said the collaboration with outside institutions looked very good (Penn State, ECI, Argonne), while another said it was hard to criticize, adding that it looks like the right organizations are involved. The final reviewer said working with industry, national labs and universities, this project has an excellent team.

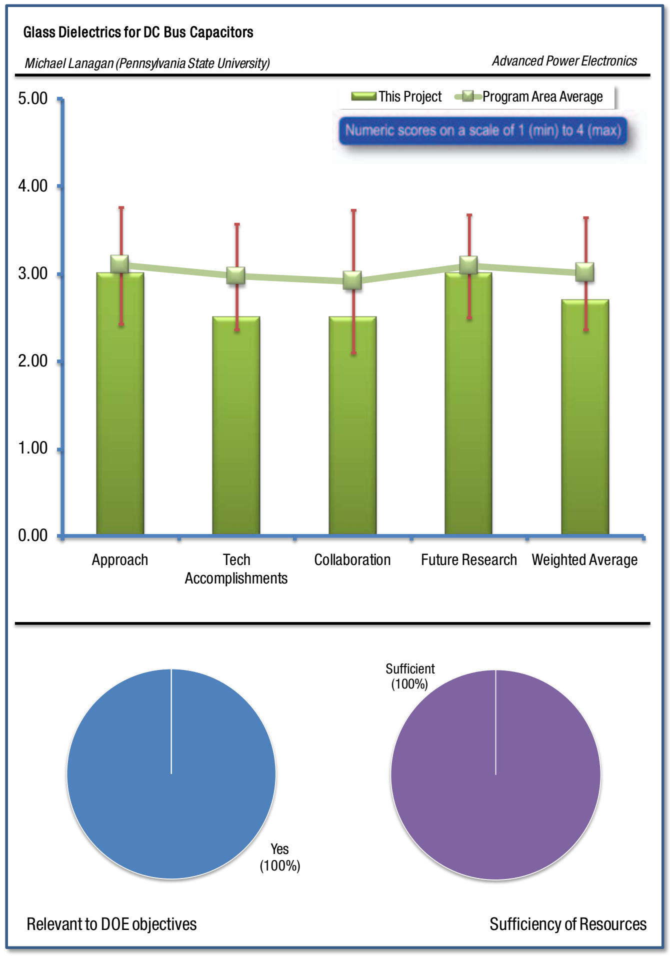
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One reviewer said the concept of thinner extruded films with higher dielectric constant is directionally correct. The team needs to demonstrate this. The other commenter said this is right down the alley as to what is needed. This reviewer asked: has the team explored other possible sources for doing the "stacked" capacitor? Would the traditional "stacked film" approach be applicable? Graceful failure is a major requirement. Consider the power that is available should a capacitor not fail "gracefully" (i.e., 450VDC bus with several hundred amps available for fault current.) This reviewer is glad to see this program better funded in 2010.

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

No comments were received for this question.

Glass Dielectrics for DC Bus Capacitors: Michael Lanagan (Pennsylvania State University)



Reviewer Sample Size

This project had a total of 2 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said that glass as a capacitor dielectric could substantially reduce size/weight, especially considering other advantages with respect to thermal management. The other commenter said low cost, high temperature bulk capacitors are needed for power electronics inverters to help enable the market for electric drive 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?

The first reviewer stated there are some magnetic aspects of a high current stacked capacitor design not addressed here, but considering the funding level this reviewer didn't think they need to be in this particular research effort. However, some thought should be given to losses if large electrode areas are connected to terminals: metal thin enough to allow self healing has limited current carrying capability and limited current density before it vaporizes in a similar fashion as around a dielectric fault during the clearing process.

The other reviewer asked whether there is a supplier of glass that can provide less than the 10µm thickness needed to make a comparable size capacitor. Is this thickness of glass, less than 10µm, required for the flat panel displays, or is this a specialty item which may make the cost of the capacitor non-competitive?

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

The first reviewer commented one supplier has been found that is making glass “wire” of the required thickness but are interested in making sheets in high volume to lower the cost and enable the technology. The other stated this work is tightly focused on self-healing effects. This reviewer would like to see the same after the capacitor is in the stacked arrangement. The proof of graceful failure is in a “usable” capacitor, where a dielectric failure and self healing succeeds without involving adjacent layers. Is there a possibility of obtaining this glass in “rolls?” A wound glass capacitor would have several advantages over a stacked form. Depending on dielectric strength, this may be useful in really thin “films,” say 3µm. Is there a possibility of that? At what voltage stress did the glass fail and self heal? This reviewer would say that these self healing experimental results appeared expensive, but more work may have been done than was presented.

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

One reviewer was not sure how, for the work presented, all of the collaborators were involved. This is likely to improve for the next phase of the project. This reviewer added it was very hard to tell with a short presentation and conversation what activity was done by collaborators. The other reviewer asked how effective it is for the team to introduce glass manufactures to capacitor manufacturers.

Would it be better to have someone who represents the market, possibly someone from the EE tech team, to work with the group and the manufacturers to help establish market size and help persuade the cap manufacturers to help develop this product?

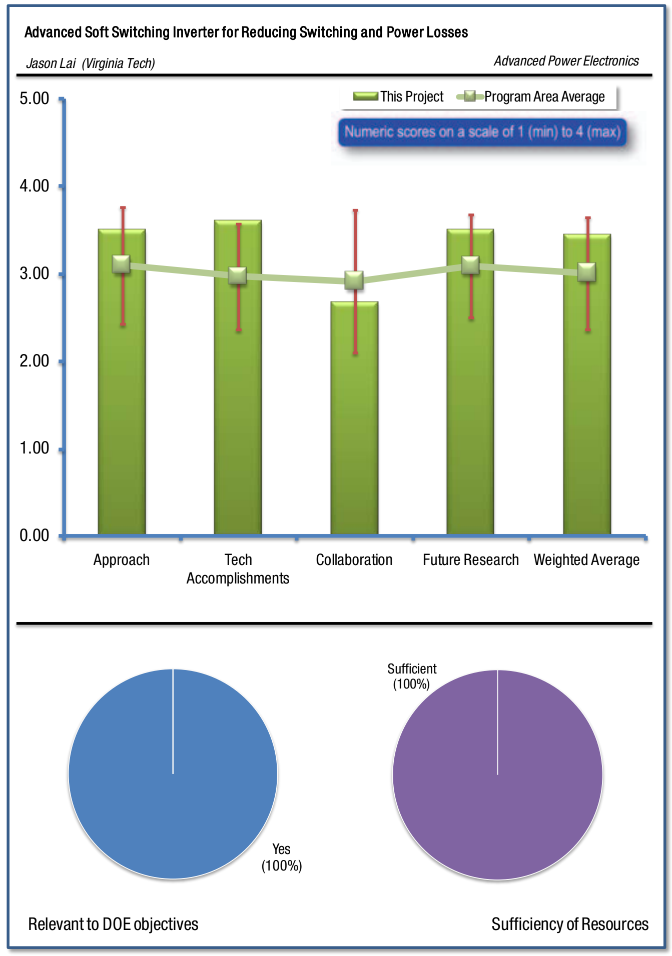
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer referred to the comments under the approach question. The other reviewer said the plan is good, and will see next year what progress is made. The team could look at availability of the thickness of glass that would be optimal for the 450VDC bus requirement. This reviewer suggests also looking at capacitor electrode thickness as well as for an optimal material.

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

No responses were received for this question.

Advanced Soft Switching Inverter for Reducing Switching and Power Losses: Jason Lai (Virginia Tech)



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said that the objective of this program is to develop soft switching inverter for traction applications with 98% efficiency or higher. This is highly relevant for hybrid and EV applications as it will lead to lower losses, and higher coolant temperatures. Another reviewer said the project is looking at reduction of cost volume and weight. Also, the project is looking at increased efficiency. The project is investigating advanced packaging that can lead to more improved system performance. A third reviewer said developing power drive technology (soft switching) to improve its efficiency is perfectly relevant. Another commenter said that the project will develop extremely high efficiency converters based on CoolMOS and soft switching. It will benefit the future electrified vehicles by saving energy. One reviewer said the project aims to improve overall inverter efficiency of 98% and peak of 99% to reduce cost, weight, volume and thermal management. The final reviewer said higher efficiency inverters allow electric drive vehicles to go farther on the same amount of energy, providing more range, or possibly less batteries for an equivalent range.

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 liked the approach of having three generations, with the next one based on lessons learned from the previous one, while another reviewer said the research involves modeling and simulation, prototype manufacturing, testing and validation, and added that the approach is appropriate. A third reviewer said the idea of using a silicon IGBT in parallel with a CoolMOS is a very good approach to reducing conduction losses at light loads. The idea of reducing loop inductance within the module is a good idea. It will be worthwhile to discuss how this was achieved. The presented material shows efficiency rising almost 1 % over a time period of 5-6 hours. This reviewer asks how this is possible. It casts doubt on the accuracy of the calorimeter. It will be nice to see a plot of inverter efficiency vs. output power.

Another commenter said there was very good work in showing efficiency and EMI improvements, but added that the cost data for the power module is questionable for the automotive environment. A fifth reviewer said the approach is technically outstanding but very complex to manufacture. The team is able to get 99% efficiency. Hybrid switch Mosfet/IGBT is made possible due to soft switching but adds additional cost. Variable timing is very innovative. Low thermal impedance module is good work but not really needed. The final reviewer commented that the module does not include the resonance inductors. The development of a soft switch hybrid module using the IGBT and MOSFET is good. The highly integrated soft-switch is good for reduction of switching losses. This reviewer would like to see the peak current through the devices.

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

The first reviewer said the project is right on target, with experimentation that supports simulation: a lot was accomplished this year. This reviewer is eager to see how Generation 2 performs in a vehicle. A second commenter said prototypes have been made and preliminary testing have concluded, and added that the progress is excellent.

Another reviewer stated that calorimeter test measurements were needed to determine accurate measurements. This reviewer added that the Gen 2 module is very complex to build but the inverter looks compact. Cost models project lower future cost, which need some more work to be believable. A $4^{o}C$ rise in T_j is outstanding. A fourth reviewer said significant volume reduction has been achieved in the Gen-2 inverter. Efficiency of 98% has been consistently achieved. Authors claim > 99%, although only one figure in the presented material shows that after 6 hours – efficiency increase with time needs to be explained if really true. One table in the presented material shows <99%. Nevertheless, the team should be congratulated in making a piece of hardware which works great.

One reviewer said the group can get a reduction in the cost of the modules. This reviewer said very significant reluctance was seen in parasitic inductance from the advanced packaging, and also reluctance in the output EMI. It is not clear at what power level the EMI plots were taken. One final reviewer said demonstrating the high efficiency and low EMI is good, but the cost comparisons need more work. The team compares their modules to a standard six pack module; the comparison should be made to an automotive qualified power module, plus the inductors that are required for the team's soft switching power module should be included into the cost.

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

The first reviewer said there was a small well-focused team, while another indicated there was good collaboration with partners for the study. As already mentioned, an industrial partner will be a plus. A third reviewer mentioned Powerex, NIST, and Azure Dynamics. Another commenter said the collaboration between the PI and Powerex is clear, but added that it is less clear between the other partners. One reviewer noted that further collaboration with industry for future commercialization is important. The final reviewer said the team did not show any outside collaboration.

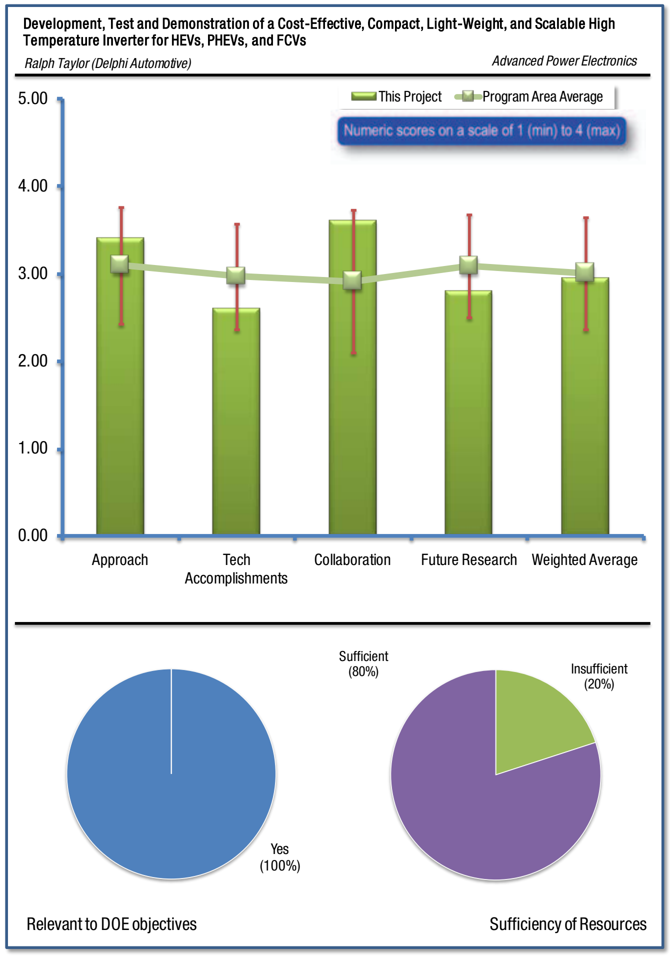
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Comments were generally positive in this section. The first reviewer said the plans to test the inverter in the vehicle are outstanding, while another said the future research is appropriate. A third reviewer said to continue testing and integration into a vehicle, and added that it is good that the researcher will address the EMI issues; this reviewer would like to see the tradeoff between the hard switched and the soft switched circuits. Another commenter said that putting the inverter on the road is an excellent test. The cost model for the Generation 3 module should be an automotive qualified module, including the cost and weight of the inductors vs. an automotive qualified power module. The final reviewer stated, according to the milestones slide, Generation 2 will be tested in vehicle. This reviewer asks, what about Generation 3?

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

No responses were provided to this question.

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



Reviewer Sample Size

This project had a total of 5 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. One reviewer said reducing cost, weight, and volume of an inverter is definitely a relevant objective, while another said that the novel packaging and possible low cost construction make this effort very relevant to the DOE objectives. A third reviewer said this supports DOE objectives for cost, volume and weight, and added that this is a broad multi-discipline approach that looks at many components. Another reviewer noted the project investigates low cost, volume and weight of the inverter circuit. The approach to reduce wire bonds can increase the reliability of the system and reduce long-term cost. The final reviewer said that the reduced weight and size, and eliminating the need for a cooling loop addressed by this project would help reduce petroleum consumption. This reviewer added that the proposed manufacturing approach would be consistent with cost effective high volume production.

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 said this program considers the broad spectrum of inverter technologies that together may have significant impacts. Specifically, the novel double-sided cooling IGBT and the circuit board integration may lead to substantial improvement. Another reviewer noted the project uses a Delphi Viper power switch with double sided cooling, and added there was great experimental work on GE extruded polycarbonate film capacitor. A third reviewer said the approach is good but challenging due to the amount of new components involved. Another commenter stated that the dual high-risk, high payback and low-risk approach is commendable, but delays in the high-risk efforts seem to have resulted in overall program delays.

The final reviewer commented no wire bonds and using a circuit board approach, which will minimize the buss bars. A very compact system was designed that can have both top and bottom cooling. Improvement on film capacitors was seen. The team is also investigating the film-on-foil caps to reduce cost and volume. Also, the team should investigate SiC devices to replace Si. There is a need to double current handling capability of SiC to keep the cost the same.

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

Comments in this section were mixed. The first reviewer said the team has good progress toward the objectives and has shown good results in the package and capacitor development, and added that they need to overcome the issue with SiC material. Another said congratulations for the effort but has to admit that it is hard to evaluate the progress accomplished due to the lack of information. A third reviewer commented that November is when hardware is available, and added that the SiC on Si work is progressing, but is not a success yet. Another reviewer was disappointed that even a preliminary inverter design has not been fabricated and tested with the

Viper IGBTs using existing state of the art Si diode and capacitor technologies. This reviewer added that it appears that the original problems associated with growing SiC on Si seem to have been solved – this is encouraging.

The final reviewer said progress is generally good on the broad set of individual tasks and on the integration of the overall project. There remains uncertainty about progress on one of the high risk, non-critical path, tasks involving SiC on Si wafers. Progress was previously made on wafer thickness and bow, but N_2 contamination is still too high. The stated goal for Q2/2010 (shortly after this Merit Review) is to determine if the new material is suitable for fabricating test devices. Although material test structures indicate progress, this reviewer eagerly awaits quantitative demonstrations of the status of this task and how it might impact the overall project.

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

Comments were generally positive in this section. The first reviewer said there was good collaboration with leaders in the market of devices packaging and circuits, while another said that there appears to be a strong team. A third reviewer said there were different partners with critical involvement. The final commenter said Delphi has put together an outstanding team of experts and companies incl. Dow Corning/GeneSiC, GE, Argonne, ORNL, and NREL.

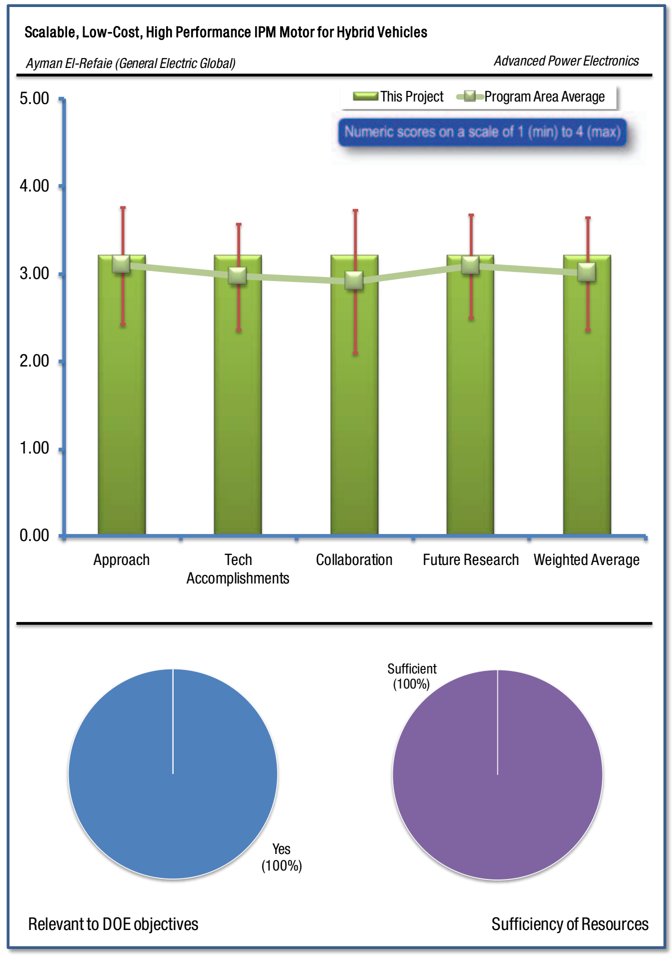
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said that many paths can be explored with these technologies. Another stated a concern that there are still a lot of unknowns, and the reviewer isn't sure that they will be addressed and solved in the small amount of time left. Backups are planned but will not plainly satisfy the expectations. A third reviewer said to investigate film caps and foil caps. The team should continue to look at 3C SiC. The team did not show many results for system modeling. The final reviewer stated that it may be too late in the program, but an inverter should be fabricated and tested with the existing Viper IGBTs and "low-risk" state of the art diodes and capacitor technologies, as well as building an inverter with the "higher risk" technologies once they become available. This final reviewer said the team seems to be betting on all of the "high-risk" technologies being successful.

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 5 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said this project seeks to meet very aggressive targets for motor cost, efficiency and weight, while another said propulsion motor technology is key to electrification success and improvements to the technology affect vehicle performance, efficiency and range. This reviewer added that efficiency and range affect petroleum displacement. A third reviewer said the work was to achieve high efficiency (greater than 95%), high speed of 14,000 RPM, and high coolant inlet temperature. The final reviewer commented that the novel electric machine design claims a significant increase of efficiency. If the project is going to be successful, the novel electric machine design could potentially accelerate the implementation of electric drive systems in the automotive industry. This would support 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 said improving each main component of the PM is certainly a good approach, while another said GE has taken an innovative approach to simultaneously meet all the goals. The design uses concentrated windings and an interior PM rotor. Another reviewer commented the approach is to reach high power density IPMs. A fourth reviewer said the researchers are addressing one of the most important technical barriers in electric machine design, which is the increase of efficiency. But it has to be checked in how far the focus on fulfilling the very tough DOE requirements for efficiency at high speed might sacrifice the efficiency at lower speed operation, which is usually more important for the overall fuel efficiency in a vehicle application.

The final reviewer said few details are provided, but the motor technology appears to be innovative. High resistivity magnets are required due to spatial harmonics created by the stator, so more evidence that the topology justifies the rotor heating would be useful. Rotor heating tends to become worse as motors are scaled up to higher power, this final reviewer added, so the team should consider this when the 120 kW version is designed.

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

The first reviewer said the test results of first generation machine are encouraging. This reviewer is impressed by the amount of work done this year. Concerning the thermal study, concerns are raised about the thermal exchange between stator and cooling jacket. This reviewer is curious to know what the liquid temperature was during these tests, and the extracted thermal power. A second reviewer commented that the team has received and tested the first proof of principle machine and has received the second proof of principle machine. There was a good approach on the stator winding to reduce the losses. The team has completed full testing at various speeds and tested up to 1400 RPM. The team has tested the machine up to full power. The machine was also tested up to 105^{o}C inlet coolant only up to 7500 RPM.

A third reviewer said that significant and partly excellent progress towards the objectives has been made. All issues have been named and for most of these a path leading to the solution has been shown. The manufacturing and testing of prototype machines gives credibility to the claimed achievements. Some of the proposed improvements for the IPM machine design can also be applied separately to other machine concepts. This reviewer adds that the concentrated stator winding concept chosen leads to higher harmonics, and therefore potentially higher losses in the rotor. This problem is addressed by a part of the project which deals with the development of new magnet materials with higher resistivity. The researchers should make sure that this part of the project is not consuming too many resources, because this specific topic is also studied in two projects from other researchers.

Another reviewer said the motor meets most of the goals except for high speed efficiency. This reviewer believes that this requirement is not a real world need since there is very little time spent at high speeds for most drive cycles. The final reviewer said proof of principle test data shows progress, but the test results are limited and more characterization should be available. For example, an efficiency map and continuous output capability curve should be presented at this time (preferably with a high accuracy torque cell like HBM).

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

The first reviewer said there was good collaboration with academia and industry to meet the requirements, while another said the collaboration between the different partners seems good. The third reviewer said that the partners are appropriate, and another added that GE has many good partners. The final reviewer said the collaboration with university and industry partners seems to be well coordinated. This gives the project the advantage of receiving input from multiple sides, which should contribute to the success of the project.

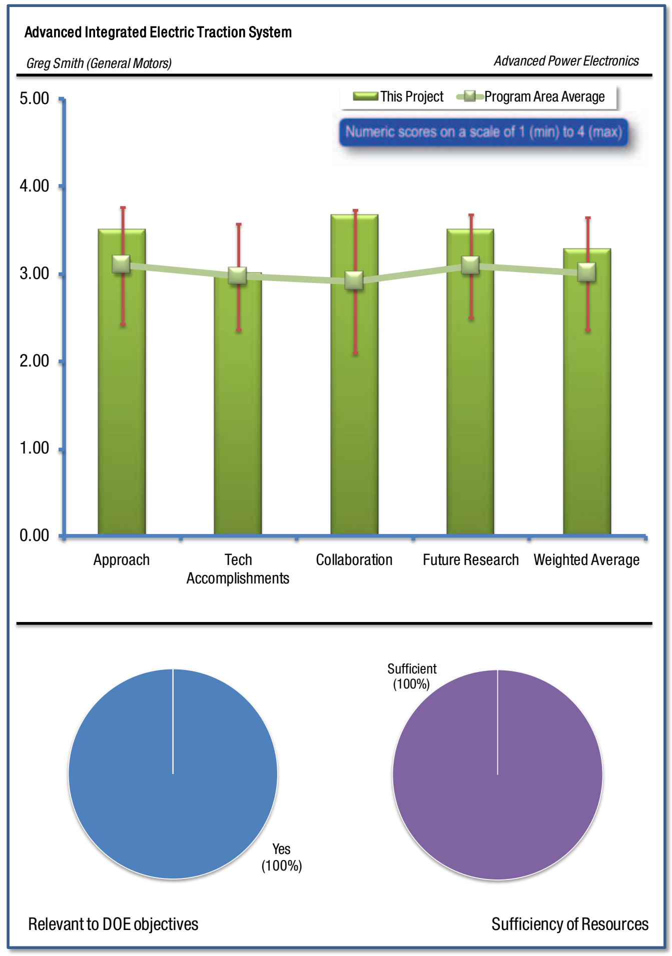
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said there was a good approach to scale up of the motors and meet the required goals, while another said the proposed future work addresses the majority of the remaining issues very well. A third reviewer said there is a good plan to cross the finish line, but asked if it will be on time. The final reviewer said evaluation of the current status and how that influences the next steps appears to be appropriate and in place. More detail for the purpose of evaluation is desired to help review the technology and determine its advantages relative to available motors.

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 6 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said this project will reduce cost with high power density and high efficiency. Also, this project addressed the increase in reliability. Another commenter said that this project, if successful, will help meet the 2015 electric drive train targets. A third reviewer said the work is directly relevant to implementation of EV or hybrid EV application; real world, right now. Another commented that integrating the inverter into the same housing as the motor is an avenue that needed investigation. A fifth reviewer said this technology ventures into areas that stray from conventional, and, if cost advantages are proven out, it will help vehicle electrification adoption. Another said smaller size, lighter weight, and cost improvement are directionally correct to enable market acceptance of electric drive vehicles. The final reviewer said this is different from university/national labs based research, but this comment is not to imply that this final researcher thinks research projects are not important. DOE funded projects often allow discovery and correction of problems otherwise uncovered by customers. This benefit may not always be appreciated.

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 said the trade studies performed to arrive at design decisions appear to be well thought out and executed. The team recognizes the issues relevant to propulsion system optimization. Another reviewer said this approach looks at components in the system such as the motor, thermal, circuits, chargers and the system integration. A third reviewer said multiple challenging innovations are sequenced in this approach (multi-phase machine, heavy layer circuit, new switches, bus caps…). Another commenter said that, given the results will be a “real product,” known barriers have to be knocked down, or at least addressed. Without this focus, that wouldn't happen. Another reviewer said the work was focused on technical barriers, but adapting requirements to “real world” environment. Can the team share those real world requirements by updating the original specifications? The final reviewer said (1) It is not clear what the key quantitative benefits are of going to 5-phase system in terms of meeting the 2015 specs, and (2) Even though the project is targeting the 2015 specs, according to the presenter, it seems that some of the components are sized based on GM's required ratings and not the 2015 specs.

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

The first reviewer was impressed by the accomplishment realized this year in this project. Each sub-system looks under control. Another reviewer said the pace of progress is impressive, and added that it would be helpful to quantify the improvements achieved based on the design decisions (publishing the trade studies). For example: capacitance reduction due to 5-phase with 3rd harmonic current, inverter kVA rating for 5-phase versus 3-phase approach, pros/cons of thermal solutions, and why the copper baseplate came out on top. A third reviewer said the progress has been excellent, but added that, considering the funding level, it should be. Cost remains a challenge, and this reviewer thinks it will be for considerable time. Cost is a real barrier to success in this market. Even with the federal subsidies for a plug-in EV, the cost differential between say a Chevy Volt and an equivalent internal combustion-only vehicle enables purchase of a large amount of gasoline. It appears that cost has been addressed in several areas.

Another reviewer said the project started at the component level, and developed a heavy copper board and press fit pin, which is done with a solder-less joint. The team also investigated high temperature solder. They tested power module joint up to 1800 cycles. They reviewed several types of thermal heat sinks and selected the copper heat sink. Another reviewer said (1) The project is tackling many areas and it is not clear how the progress accomplished compares to the 2015 specs, (2) Test data is needed and clear comparison to the specs is needed, and (3) It is not clear what the next steps are in order to meet the 105^{o}C coolant inlet temperature requirement as well as efficiency requirements for the motor. The final reviewer said hardware is becoming available to test – perhaps for initial systems, soldering can be used as opposed to press fit pins. All targets may be difficult to make; can these "targets" be revisited as part of the task team roadmaps – Or is there a path to address these shortfalls? The presenter made the comment that a five phase motor would be something they would not put into production but they would use a three phase machine, why? What are the cost drivers that are making it difficult to meet cost?

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

The first reviewer said the team has good collaboration for the different components and a good plan to integrate the team, while another said there was a very ambitious coordination effort with all the collaborators involved in this project: good job. A third reviewer said lots of suppliers were present. Another commented that other institutions are mentioned, but their influence is unclear. Regardless, this reviewer added, the design decisions are thoughtful as mentioned above. A fifth reviewer said there are many entities involved, but it is not clear what is the specific contribution of each of them. The final reviewer commented no project like this can be successful without the collaboration of suppliers and National Labs.

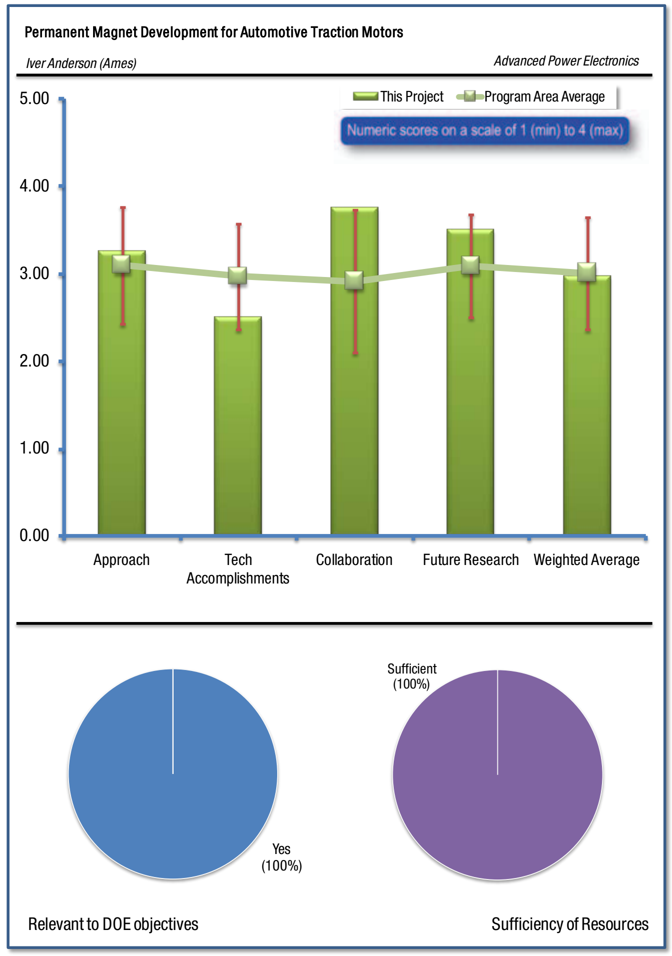
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first reviewer said future work will involve testing at the component and the system level. It should also include EMI testing and thermal cycling of the components. Another reviewer looks forward to the test results, and, hopefully, more details about the gains achieved with this architecture. Future efficiency mapping was mentioned, which is important to compare and contrast the performance of electric propulsion systems. A third reviewer said the development plan is well constructed up to the final report, while another said there needs to be experimental verification of the predicted performance as soon as possible. Another commenter said this work is to build, test and validate: not exactly research, but it is needed to verify all the previous work. The work looks good. The milestone chart says the work will be done in March 2011, the strategy chart says done in May 2011 – what is changing? The final reviewer said the proposed work appears to be sufficient to "finish the project."

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said this project focuses on the reduction of the cost of permanent magnets, and achieving higher operating temperature while maintaining magnetic performance. The goal is to increase magnetic energy density at reduced manufacturing cost. Another reviewer said the project addresses a major issue of today's electric machines, which is the high cost of rare-earth permanent magnets. If the project is going to be successful it could potentially accelerate the implementation of electric drive systems in the automotive industry. This would support the DOE objectives of petroleum displacement. A third reviewer said (1) High energy product high-temperature permanent magnets are needed to achieve high power density motors, and (2) Non-rare earth permanent magnets are needed to minimize the risk of price and availability of rare earth permanent magnets in the future. The final reviewer said current and future work is relevant to finding alternative materials, or at least reducing dependence on materials that may become difficult to obtain as vehicle electrification takes place. China's monopoly over rare earths may threaten electrification activities.

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 said this project has a good approach of developing anisotropic magnets for compact high torque applications, and added the approach using nano-crystalline powder is good. Another reviewer said that the technical barriers for the improvement of permanent magnet materials are clearly addressed by the researchers. The great bandwidth of possible improvements for rare-earth magnet material, both sintered and bonded, is covered in the approach to perform the work. Beyond that, also the improvement of non rare-earth magnet material will be investigated in depth. A third reviewer commented that past work has provided a basis to achieve results that may have a high impact going forward. Dysprosium reduction, higher strength/temperature magnets to reduce rare earth magnet content per motor, and non-rare earth technologies are important goals that are part of the future approach. The final reviewer thinks all the areas that are pursued are important but is concerned that pursuing all these in parallel might not be the way to go. Even though the presenter indicated that more resources are available, the reviewer thinks that picking one or two areas to focus one might be more productive. This reviewer is also concerned about the pursuit of bonded magnets because they have lower energy product and there are some significant practical issues that does not allow taking advantage of injecting these magnets into IPM rotors.

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

The first reviewer said the project showed good technical accomplishments in the area of simulation and development of the materials and in investigation into beyond rare earth magnetic. A second reviewer said a significant progress has been made towards the goal of improving anisotropic magnets both with intrinsic and extrinsic sintering. The main focus for this part of the project is an increase in energy density and coercivity with the reduction of the most expensive rare-earth materials. The second part of the project which deals with the improvement of the magnetic properties of bonded magnets has to overcome some technical hurdles at this point in time. The last part of the project, which is the development of non rare-earth materials, is in an early stage now and the evaluation of the technical accomplishments will be clearer next year. This reviewer added the researchers should make sure that the improvement of ferrite magnet material will be investigated in detail.

A third reviewer couldn't quantitatively evaluate the technical accomplishment and progress. This reviewer believes that clear quantitative comparison to the state of the art is needed. The final reviewer said past work has been slow to show results that impact magnets used in motors. For a program that has been going for many years, it is disappointing to see the problems encountered for achieving the fundamental goals. This is difficult science, however, which should be considered. Future work, as described in this year's presentation, and with some successes, will change this assessment.

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

Comments were generally positive in this section. The first reviewer commented that there were great collaborations and the workshops on the projects helped focus the project, while another said it seems there is good collaboration with various entities. A third reviewer said an impressive network of collaboration partners has been set up for this project. Both industry and university input will be collected in the project. This is the best approach to initiate a competitive permanent magnet research activity in the U.S. The final reviewer said collaborators are appropriate and numerous. Ames is proactive in discussing their research and soliciting input. This will continue to be important with the new directions being pursued, and input from motor manufacturers beyond those listed as collaborators is encouraged.

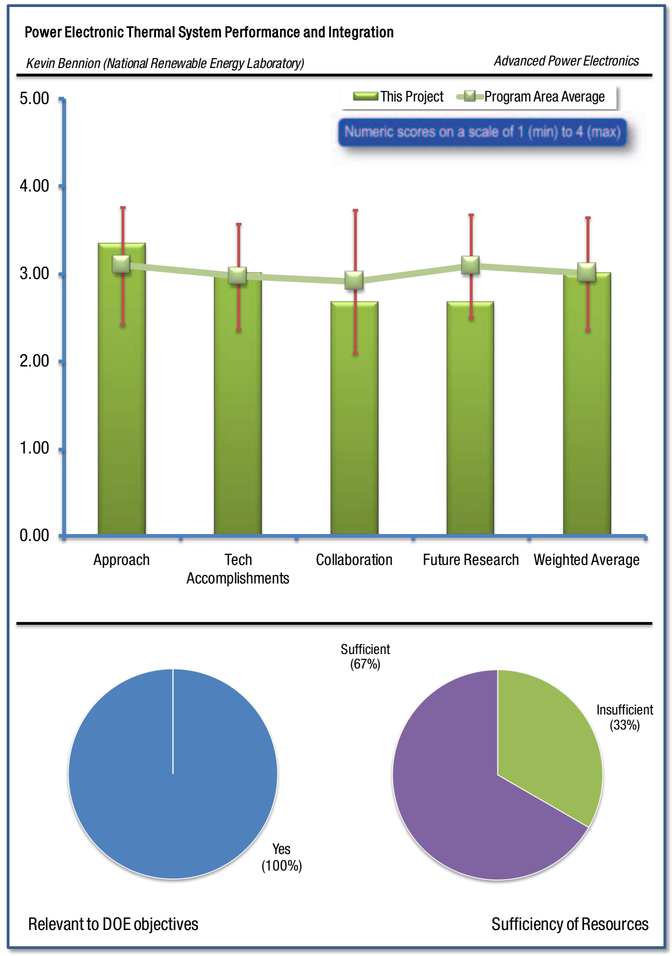
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said the project showed a good path forward to reach the goals. Another reviewer said that the future research for the improvement of sintered and bonded rare-earth permanent magnet materials is well planned and builds upon the achievements so far. The investigation on non rare-earth magnets is in an early stage, but the next steps for a more defined definition of the project are well described. A third commenter said, as previously mentioned, more focused approach is recommended. The final reviewer said past activity provides the experience to create high-impact work by reducing dysprosium and rare earth content required by high performance motors. Substantial reduction in dysprosium would be a successful result. Making AlNiCo work, somehow, would be an even more successful result. The future research proposed is important, and this final reviewer hopes next year's presentation will show progress in these areas.

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

No comments were received in this section.

Power Electronic Thermal System Performance and Integration: Kevin Bennion (National Renewable Energy Laboratory)



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said high temperature operation is critical for power electronics and high power density. Also, the package is critical for heat removal and low losses. A second reviewer said the capability to perform system studies is very important to assess the impact of different package and cooling designs on the inverter, motor, etc. The final reviewer said that competitive assessments provide a benchmark against which other approaches can be compared. These comparisons raise the bar for cost, performance, and innovation.

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 said there was a good understanding of what is needed and a good approach to developing a system-wide understanding. Another commented that the project is to identify system knowledge gaps and then develop a process. The project also investigated the comparison of baseline cooling to a direct cooled base plate and directed cooled DBC. The final reviewer said performance, weight, thermal management, and volume in some ways are being addressed. Cost and life analysis are missing. This reviewer asked if these analyses can be quantified to the goals of this program (dollar savings, weight savings, and long term reliability) with respect to how they apply to an inverter or DC-DC converter or a power stage.

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

One reviewer referred to comments from questions 1 and 2 above, while another observed that the team made significant progress towards the integration of the package and also implemented lessons learned.

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

The first reviewer said there is collaboration with industry and government labs, but not research with universities. The other commenter said more interaction with industry would be welcome. This reviewer asked whether the team can use their techniques to come up with “better ways” to do what they are benchmarking. If so, can some of their concepts find a commercial partner to use the technology?

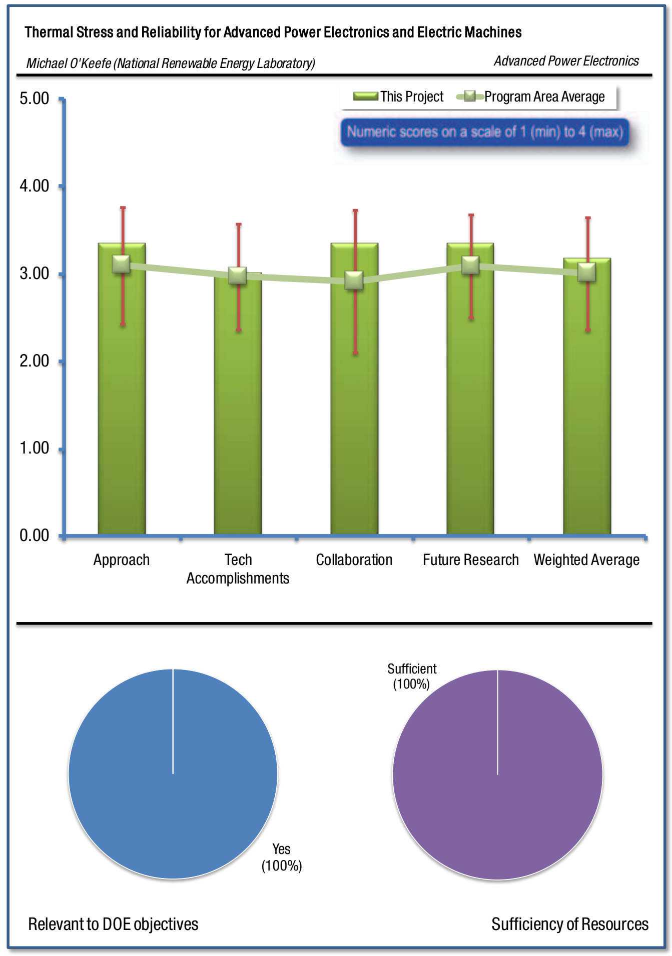
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first reviewer said there was a good plan to integrate thermal systems to meet the stated goals. Another said good work has been done establishing this modeling capability. This reviewer asks how it can be made available to government or industry in the future. The final reviewer asked if the team can come up with better ways to do what they are currently benchmarking.

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

No comments were received for this question.

Thermal Stress and Reliability for Advanced Power Electronics and Electric Machines: Michael O'Keefe (National Renewable Energy Laboratory)



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said the project focused on the development of reliability of power electronics and motors, while another said this project begins the process of understanding joint technology for power modules. The final reviewer commented that reliability evaluation of advanced technologies is essential to determine suitability for vehicle applications. Technologies evaluated in this project may aid in reducing size and weight, and in eliminating a cooling loop. This would lead to 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?

Comments were generally positive in this section. The first reviewer said the approach to compare the three APEEM packages and compare the results with the FreedomCar EETT is a good approach. Modeling was done to compare the different packages; however, some actual data is needed. Another commenter stated that this project is providing a strong theoretical and measurement foundation for package technology reliability studies within the Vehicle Technologies Program. The final reviewer said that the work is well planned, and added that the team may want to consider how best to make the data generated usable to industry.

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

One reviewer said the concepts have been demonstrated and results are described clearly. Another reviewer said good models were developed, but more test data is needed for collaboration of the models. This reviewer stated the need to show the thermal cycling of the system.

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

Comments were generally positive in this section. One reviewer pointed to a good mix of industry, academic, and other national labs, while another said the project has a strong effort to coordinate and build links between various device, package, and cooling efforts within the Vehicle Technologies Program. The final reviewer stated that there was good collaboration with industry and universities, and mentioned the collection of data from research partners to help with the generation of models.

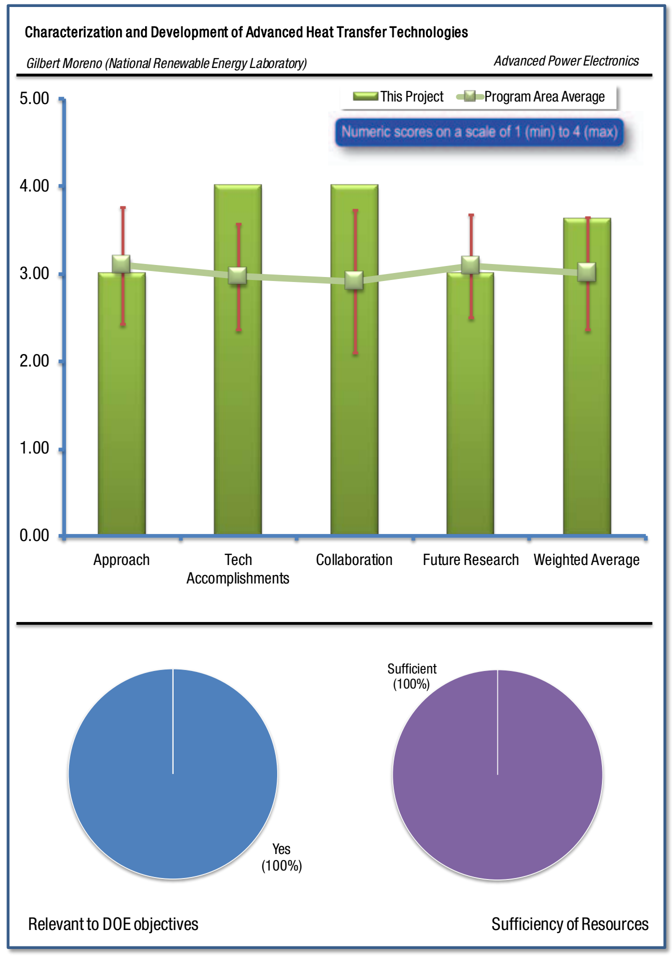
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One reviewer stated that future plans to validate model with test data will enhance the results of the research. Another said the program is well thought out with good future plans. Coordination with other projects within the Vehicle Technologies Program should continue to identify critical reliability issues and advanced structures being considered. Issues related to funding ramp up (and increased level of effort) next year should be a focus. The final reviewer said this work has a great plan, but the team needs to be timely with getting tasks done and information out.

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

No comments were received for this section.

Characterization and Development of Advanced Heat Transfer Technologies: Gilbert Moreno (National Renewable Energy Laboratory)



Reviewer Sample Size

This project had a total of 1 reviewer.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The reviewer said that improving thermal performance of inverters for electric drive vehicles can help to reduce their cost, adding that lower cost inverters can help to enable the market for electric drive 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?

The reviewer said that the team is looking for the "best" performance, but the reviewer did not see a target(s) for performance they are trying achieve. Have they considered that the best performance might be too costly, while something with lower performance may achieve the targets at lower cost?

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

The reviewer said that performance at start of life does not equate to performance at end of life. How will this be quantified? Can the team also look at robustness – diameters vary over time, distance between objects have a tolerance, coolants degrade – how does that affect the initial performance?

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

The reviewer stated that there is a good set of partners.

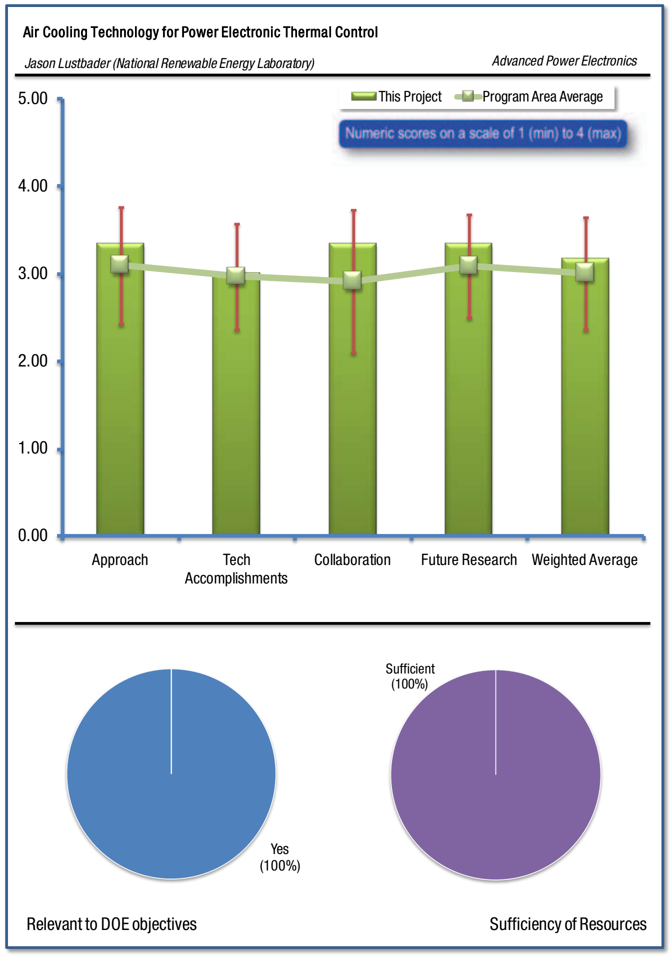
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The reviewer said to see the comments above. Can the team find a partner to implement one or more of their best concepts to show cost and performance results?

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

No comment was provided for this question.

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



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said the project supports DOE goals for cost and mass, while another said that finding a lower cost cooling system for power electronics can help to enable electric drive vehicle systems. The final commenter said the elimination of costly secondary cooling systems in HEV and PHEV vehicles is a primary goal of the overall vehicle power technology program. This reviewer added that this project is focused on optimization of air cooling approaches, with an outstanding systems integration approach, which may significantly impact these objectives.

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 said there was an excellent project focus and approach toward evaluating leading air-cooling technology approaches with an emphasis on the systems-level boundary conditions and impacts. This reviewer also observed a very well structured approach with well-defined milestones and solid technical underpinnings. Another reviewer commented that prior work on micro-fin coolers was not as practical due to issues with clogging and high pressure drop. The new work on synthetic jets looks promising to improve thermal transfer. The final reviewer said novel micro fins may give the best performance, but asked how the group addresses fin fouling or clogging. Will this require additional filtering of the air and also additional costs? Would it be possible to look at what could be done with radiator fin stock as opposed to micro fins? This reviewer added that radiator fin stock is currently used in automotive applications; its cost and properties are known and may provide a quicker path to automotive customer acceptance.

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

The first reviewer said the project is on schedule with identified milestones and go/no go metrics satisfied. A second commented that so far there is only analysis and no experimental results. This reviewer is very interested in the results: this reviewer was involved with some work on submerged oscillating liquid jets, and it showed improvement over stationary jets. It should work the same with air. The final reviewer asked how air cooling affects mechanical packaging in an inverter. Does the power stage packaging, switches, need to change to accommodate these concepts? Will that add cost to the overall inverter? How flexible can the design be; is it quiet enough to put in the passenger compartment, will it require filters that require changing?

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

One reviewer said working with ORNL to integrate the team's cooling system with an inverter is a good start. Another reviewer said the only recommendation would be to closely evaluate the work which has been done and is ongoing across DoD. This reviewer adds that DTIC reports would be an excellent resource for reference.

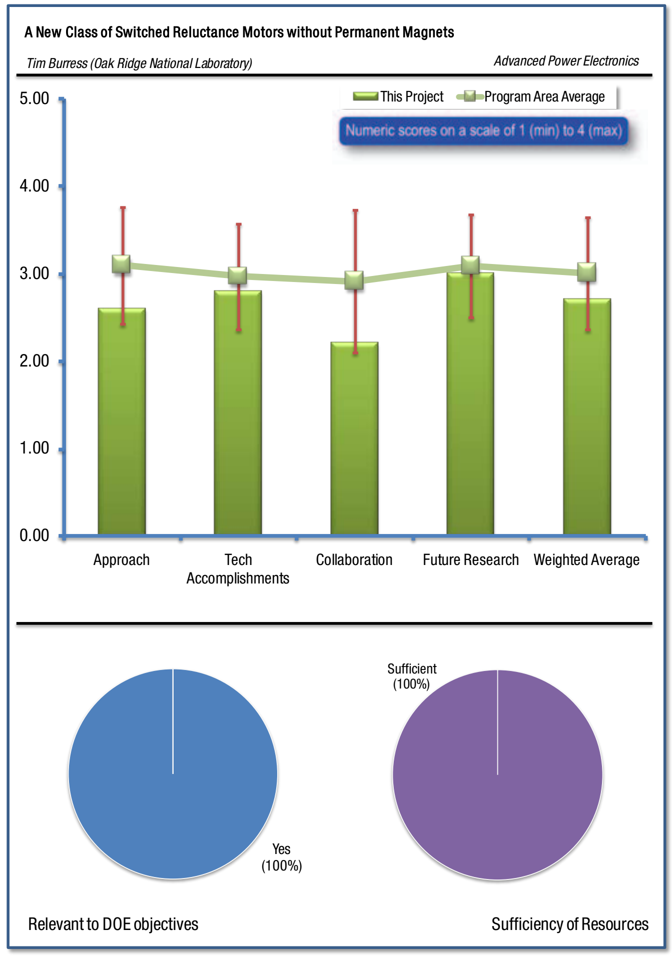
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first reviewer said that difficulties in implementing air cooling technologies appear to be well understood and the project structured to address and evaluate the proposed approach effectively. The close coupling with system level aspects will lead to a project focused on the key elements to overcoming the technical barriers present. Another reviewer said to include integrating the team's air cooling system with an inverter. The presentation should show all parts required for the team's system to work. The team should compare cost and size of all components required for air cooling.

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 5 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. One reviewer stated that, if successful, this project can provide a cheaper alternative to PM machines. Another commented that the study of a new type of switched reluctance motor is part of the contribution of new EV and PHEV. This reviewer added that the switched reluctance motor should not be neglected. Another reviewed stated that the novel switched reluctance motor design concept addresses a major issue of today's electric machines, which is the high cost of permanent magnets. If the project is going to be successful, the novel switched reluctance motor design could potentially accelerate the implementation of electric drive systems in the automotive industry. This would support the DOE objectives of petroleum displacement. A fourth reviewer said switched reluctance motors are candidates for electric propulsion and deserve to be considered if their performance problems can be overcome. They eliminate the need for strategic materials and could increase vehicle electrification if successful. The final reviewer added that this project supports the DOE cost and power density goals for electric machines. It strives to eliminate the costly NeFeB rare earth magnets.

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 said the researchers want to address the well-known disadvantages of switched reluctance motors, which are vibration/noise and controllability. The proposed design approach features some novel ideas which require a detailed investigation through simulation and testing. Another commented that, from simulation to prototyping, the approach is good, even though not a lot of detail provided. The third reviewer added that the approach seems well conceived, but results are short on details. For example, this reviewer adds that design studies of different architectures are mentioned, but the results of these studies are not published.

Another commenter stated that Tim's investigation into a new switched reluctance motor proves that there can always be new discoveries if one takes a fresh approach. This reviewer is not a big fan of switched reluctance, but this motor appears to have good torque density and low ripple. The stator poles look very simple to wind and assemble and the rotor is simple and robust. The large number of poles should help reduce modal vibrations in the stator to reduce acoustic noise. Drawbacks this reviewer sees are: 1. potential acoustic noise if the stator poles are not rigidly held in place, 2. unique power module with unidirectional current (same for all SRs), 3. twice the number of motor cables compared to 3-phase, and 4. difficult current profiling.

The final reviewer was not sure that the proposed concept can fundamentally solve the well-known issues of switched reluctance motors in terms of acoustic noise, vibration, and torque ripple. This reviewer is also not sure that the proposed concept will be competitive with permanent magnet machines in terms of efficiency and power density.

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

The first reviewer stated that the analysis of the chosen design is progressing at a good pace. This reviewer added to make sure to consider the mechanical challenges associated with the separate stator segments, as the forces on these segments could create challenges, and possibly prototype failure, if not addressed. Another said the project seems to progress properly but added that there is not a lot of information to judge it other than promising investigations. This reviewer would have appreciated having a brief description of challenges and issues solved on the motor control side.

A third reviewer said that the technical accomplishments so far are more of a theoretical nature, although some simulations have been conducted. The main claim of noise reduction is not yet proven, either in simulation or with testing. But this is fully in line with the project schedule and therefore not a point of criticism. This reviewer added that a common problem with switched reluctance motors is that if the controls are optimized for low noise, the efficiency is reduced too. The researchers have to make sure that this is incorporated in their design process. Another reviewer added that so far this project has only done simulations and no machine has been built. The technical results look promising; however, this class of machine seems to always have certain issues around torque ripple and acoustic noise that only surface after the hardware is built. This reviewer will wait for the experimental results to see how well this motor works compared to the simulations, and hopes it works well.

The final reviewer stated that, even though the project is almost 50% done, there is a lot of work to be done and significant risks to be addressed. The reviewer indicated: (1) Detailed thermal analysis should be performed. There might be significant cooling challenges with the proposed stator structure and winding configurations. (2) Detailed structural analysis should be performed. (3) Evaluation of the efficiency and power density should be performed. And, (4) It is not clear how does the machine performance compare to the specs

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

Comments in this section were mixed. The first reviewer stated that the collaboration with university and industry partners seems to be well coordinated. This gives the project the advantage of receiving input from multiple sides, which should contribute to the success of the project. In contrast, another said it’s not really a collaboration, but more on the level of sanity-check partners. A third reviewer said it doesn't seem that there is a lot of collaboration. Most of the work is done at ORNL. Another commenter stated that collaboration is light and deficient of industry/manufacturing involvement. Switched reluctance controls will be highly important to showing useful results, and partners with this experience under their belt are encouraged. A final reviewer thought that collaboration with Newcastle University or Aachen University would be very useful as both of these institutions have extensive knowledge of switched reluctance motors

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?

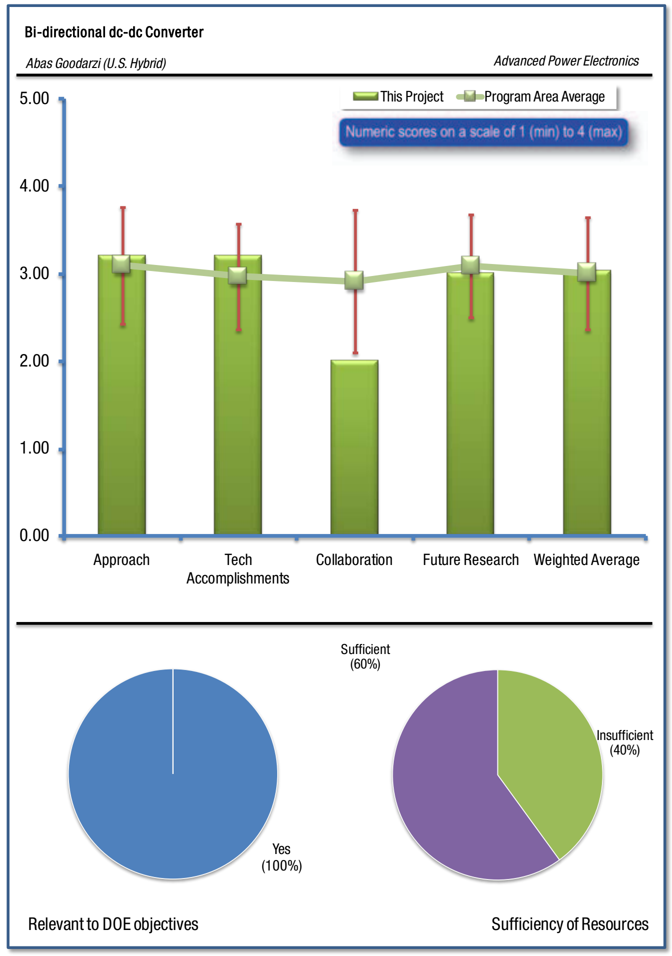
The first reviewer said the team has planned well for the project and future hardware, while another stated that the next steps in this project are well planned. The researchers are aware of the many hurdles they have to overcome to significantly improve the existing switched reluctance motor concepts. Prototype testing will be necessary for a final conclusion because an accurate simulation of the noise in electric machines is still a challenge.

A third reviewer hopes to see results from experimentation next year. Another commenter said that the detailed analysis should be finalized, then a prototype should be built and tested as soon as possible to prove the concept feasibility. The final reviewer stated that, as with any motor, and the switched reluctance motor in particular, the proof is in the testing. This reviewer would encourage a path that creates a proof-of-concept unit faster than planned, performing control optimization with hardware rather than through computer modeling.

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

No comments were received for this question.

Bi-directional DC-DC Converter: Abas Goodarzi (U.S. Hybrid)



REVIEWER SAMPLE SIZE

This project had a total of 5 reviewers.

QUESTION 1: DOES THIS PROJECT SUPPORT THE OVERALL DOE OBJECTIVE OF PETROLEUM DISPLACEMENT? WHY OR WHY NOT?

The first reviewer said the work supports the DOE goals for cost, mass and weight, while another said it meets or exceeds DOE targets for PHEV bidirectional DC/DC converters. A third reviewer said DC/DC converters are and will be more and more necessary on EVs and PHEVs due to the multiple DC voltage sources necessary. The final reviewer said bidirectional DC-DC converters are becoming more popular in HEVs and PHEVs due to their importance in reducing battery current ripple, maintaining power capability of the motor, and increasing battery life time.

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 said moving from simulation to prototype is a classical approach, but still very appropriate to that type of development. Another said current PHEVs do not advertise a dual battery approach, and asked if there is an OEM that is interested in the team's concept. A third reviewer said the concept of combining a power battery and energy battery makes sense until a better battery comes along. The key to this approach is a high power, high efficiency DC-DC converter. This converter uses SiC and multiple sections to increase efficiency. The final reviewer said the approach uses two kinds of battery packs with one directly connected to the motor DC bus while the other uses a DC-DC converter. It might work in some way, but why aren't all batteries connected through the DC-DC converter?

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

The first reviewer said the measured data shows very good results in improving vehicle range, converter efficiency, and cost. There are few details about the converter design, but it is obvious that careful details of magnetics, thermal and power flow were completed. Another reviewer said a lot of simulation has been done at vehicle level and also at the component level. Test realized at component level on units is a good accomplishment so far, especially when results appear clearly; this reviewer can appreciate that. A third reviewer said the progress seems to be slower than expected. The final reviewer saw no comments on the power density and specific power targets, and this reviewer asked, were they met?

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

The first reviewer said it appears that most of the work was done at US Hybrid, while another reviewer cannot see any collaboration or partnership in the presentation. Another reviewer indicated no obvious collaborations, and added that the team seems to be seeking a partner for vehicle testing. A fourth reviewer said the team does not seem to have true partners for implementation of the developed converter. It is important that the researchers work with an OEM and a Tier-1 supplier in order to validate their research results. The final reviewer asked if the team can find an OEM and a battery supplier who are interested in supporting this architecture.

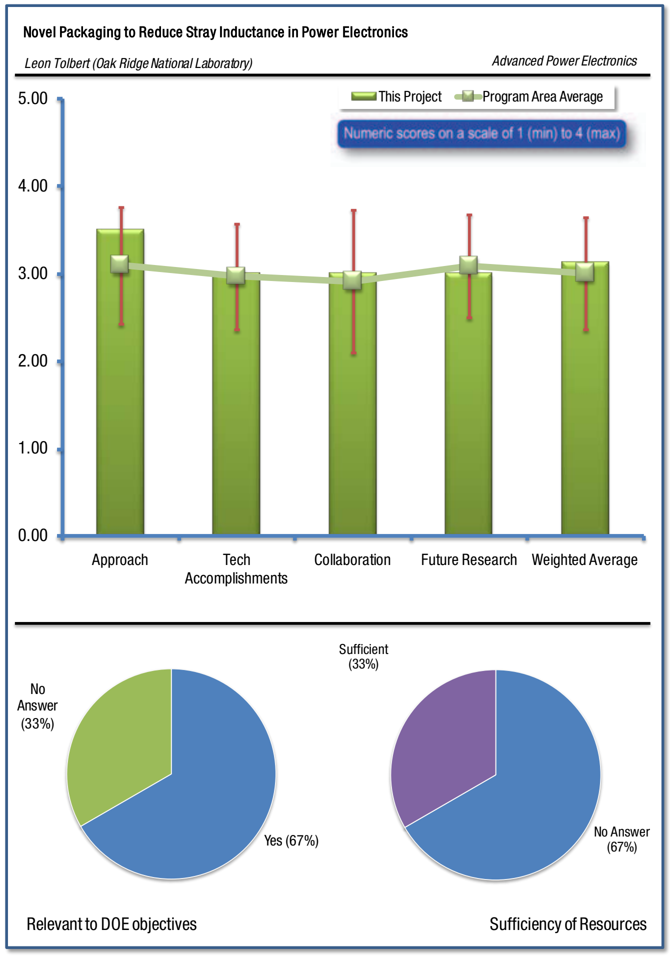
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said the future research objectives are okay, while another commented that the intent is really to fully validate the product and bring it to production: that's an excellent objective. Another reviewer said they seem to have a commercialization plan for multiple applications, while a fourth reviewer referred to previous comments above. The final reviewer said that based on the current results, this project should continue into the pre-production phase or at least additional applications.

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

No comments were received for this question.

Novel Packaging to Reduce Stray Inductance in Power Electronics: Leon Tolbert (Oak Ridge National Laboratory)



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said this project is designed to reduce stray module inductance. This has a minor effect towards meeting DOE goals. It is a good way to increase module reliability. Another commented that the poster was not presented during the review. The final reviewer said power modules with low internal inductances reduce voltage stress levels on the semiconductor die as well as other components and materials in the system. However, the reviewer added that most power module suppliers already have low inductance package designs.

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 said this was a novel concept, but added that there is a problem with the "proposed" configuration shown in the presentation materials. This configuration implies that the Si PiN diode has the anode connection on the bottom of the chip and the cathode on the top. The opposite is true for silicon PiN diodes. Although this issue is not unsolvable, this reviewer added, the solutions may not be very practical. The concept of P and N cells is relatively new to the next reviewer, and it makes sense that it can reduce the parasitic loop inductance in a module. The simulations look very promising for the one case shown. In this reviewer's opinion, the investigators should be working with a module manufacturer to understand their needs, standards, and barriers. They may be doing this already. Drawbacks are: 1. difficulty scaling up to multi-chip switches with current sharing imbalances, and 2. DC bus pads are located in the center of the substrate which makes it difficult to wire bond to a lead frame. This reviewer believes that this is a good idea, and is anxious to see test results.

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

The lone commenter did not see any evidence of design sensitivity studies, i.e. internal inductance variation with conductor width/spacing/length, length and number of wirebonds, etc., different chip layouts to drive design of test module.

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

There were no comments in this section.

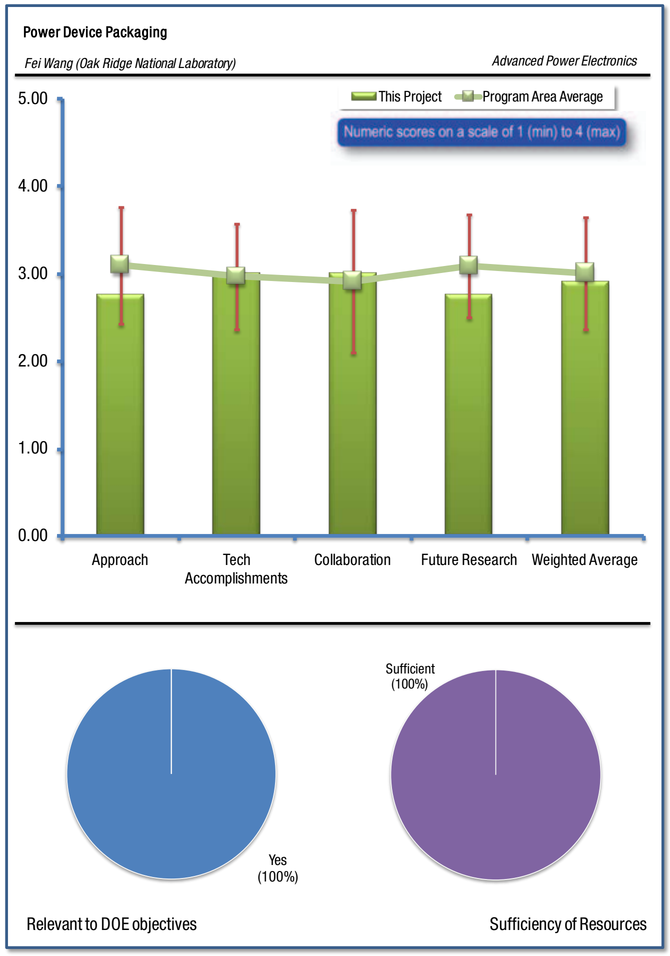
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

There were no comments in this section.

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

There were no comments for this question.

Power Device Packaging: Fei Wang (Oak Ridge National Laboratory)



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said this project looks at power device packaging, which is important to meet the DOE goals of cost, volume and mass. Another stated that developing new power packaging can lead to smaller size lower cost inverters, helping to enable the electric power train market. A third reviewer commented that advanced high temperature power device packages with high reliability may impact the size and weight of the vehicle inverter and eliminate the need for an additional coolant loop. The final reviewer said the power switches are going to be one of the biggest challenges to overcome for inverters.

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 said benchmarking to establish a baseline before studying new solutions is a smart approach, while another commented that this is a new start-up that seems to be entirely exploratory and open ended without a clear predefined technical approach. A third reviewer said it is good to benchmark the best of power devices available today, and added that this benchmarking activity is just starting. The final reviewer said that, since the project is under patent review, it is difficult to evaluate. The approach to benchmark existing designs, improve on their performance with new designs, build and test those new designs is good.

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

Comments in this section were mixed. One reviewer said the project has made progress on performing some tests on state-of-the-art vehicle power devices. Another commented that no new concepts for a novel packaging method were shown. A third reviewer said the project is in its early stage. This reviewer noticed that some results extracted from other projects already mature, but “that's fine” to use previous work to move forward faster. The final reviewer said this was a new start – since the project is under patent review, it is difficult to evaluate. Work shown has many coolant seals, this reviewer noted; how are leaks prevented?

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

One reviewer said ORNL is used to managing programs with diverse collaborators, while another said appropriate collaboration partners are identified, but not much strategic collaboration has been demonstrated yet. The other commenter asked if the team should be working with a semiconductor supplier to provide die for their packaging work.

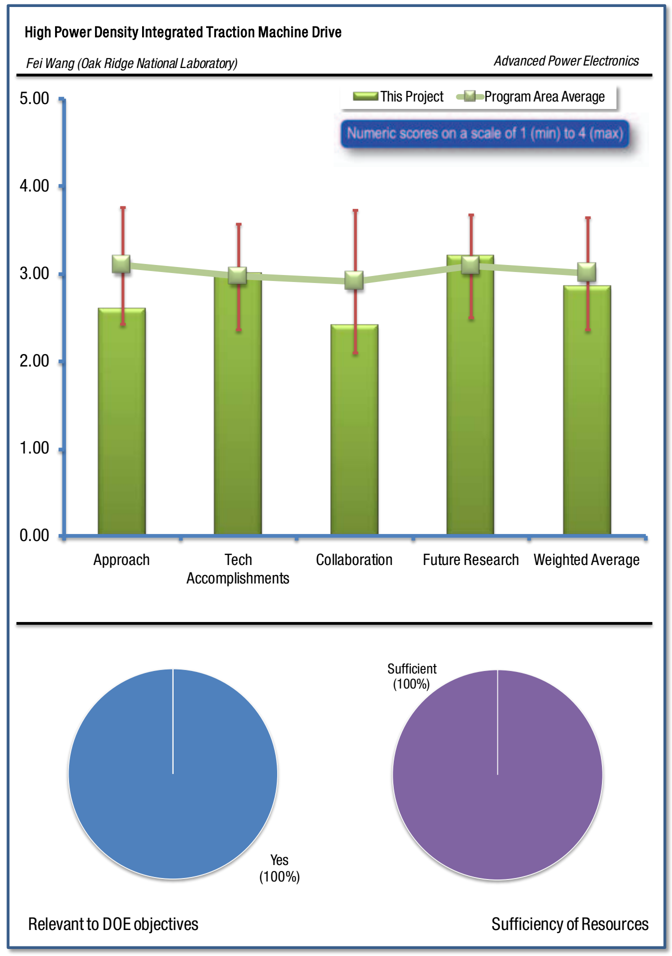
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first reviewer said this was a new start and referred to previous comments, while another was curious to see how the new package concept will go. This reviewer would have appreciated some status of development or research in progress concerning the new package concept. Another commenter said this project needs to continue to develop a more definite plan for addressing identified technical challenges. This may improve as the project progresses. The final reviewer hopes that the team comes up with a workable power concept, and added that there needs to be tight cooperation with commercial vendors to understand production costs.

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

No comments were received for this question.

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



Reviewer Sample Size

This project had a total of 5 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer stated this work supports the DOE goals of system cost, volume, and mass, while another said methods to decrease the cost of electric drive vehicle traction drive systems can help enable the electric drive vehicle market. A third reviewer commented that integrating the motor and the power converter can have a significant impact on reducing the drive train weight and volume. Another commented that integrated motor/electronics solutions are desirable for vehicle electrification and could increase consumer adoption. The final reviewer said this project concerns the electric propulsion system, which is necessary to the petroleum displacement objective. The limited power capability of such integrated drives is, however, a concern.

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 noted this project has just started and a prototype is already on its way. This reviewer cannot see any proof of concept or simulation, however, and asked if this project corresponded to the continuation of previous work. Another reviewer commented that an integrated traction drive is appealing, but this project takes on a lot of challenges that make it difficult to envision a manufacturable approach. Even if only some parts of this work are taken forward, this program will be worthwhile.

A third reviewer asked if the team can explain how packaging design and optimized cooling systems will extend operating junction temperature to 200°C. Are they saying this concept will work with all IGBT devices? Why oil cooling, why not use water-ethylene glycol and get better performance? How does this 200°C junction temperature affect the life of the device? What does the team feel is limiting the current Si device junction temperature?

Another commenter said the objective of this project is an integrated motor inverter. This is a unique approach because it also uses a multi-phase motor with a separate inverter per phase. This brings redundancy to the system, but also adds parts and complexity. If integration was not enough of a problem, they are also attempting to operate at 200°C junctions. Drawbacks are: 1. low B_{max} for the soft magnetic composite pole piece, 2. difficult cooling of the system, and 3. no thermal margin on power devices. The final reviewer said the scope of the project is not well defined. It is not clear whether the project is only focused on the integration and packaging issues, or if it will also include motor development. Also, it is not clear whether fault tolerance is one of the objectives or not. This final reviewer said many things still need to be decided.

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

The first reviewer was really impressed by the progress made on this project in a short period of time, and said “good job.” Another commented that this was a new start, and to see comments above. A third reviewer said having hardware early on as a demonstrator is a real positive. This reviewer added that more information and results are encouraged, but as a new program, this should not be expected during this review.

Another reviewer recommended they investigate 3D laminations that are now being done by several Japanese lamination suppliers. They use progressively stamped laminations of various shapes to create a laminated stack with 3D features. This can give them the desired 3D pole piece made of thin magnetic steel material. Another recommendation is to either reduce the coolant temperature or consider air cooling for the power electronics.

The final reviewer said one of the key accomplishments is developing control for the 5-phase system, and added that this might not be very relevant if it is decided not to pursue a 5-phase system. It seems that the main reason why 5-phase was pursued is mainly legacy and the existence of a 5-phase machine. This reviewer added that the other accomplishments, in terms of device evaluation and device packaging, still seem to be at a relatively preliminary stage. Experimental results are needed. It is not clear what is being done on the motor side.

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

One reviewer said the work load is well distributed between universities used as subcontractors: "smart play." Collaboration with a semi-conductor company would have been a plus for this project. Another reviewer said it seems that most of the new work is taking place at University of Tennessee, and added the main contribution of University of Wisconsin seems to be providing the 5-phase IMMD that has been previously developed. A third reviewer said collaboration with organizations that have hands-on experience in some of the key innovation areas would be helpful. The final reviewer would like to see an Si supplier supporting this work.

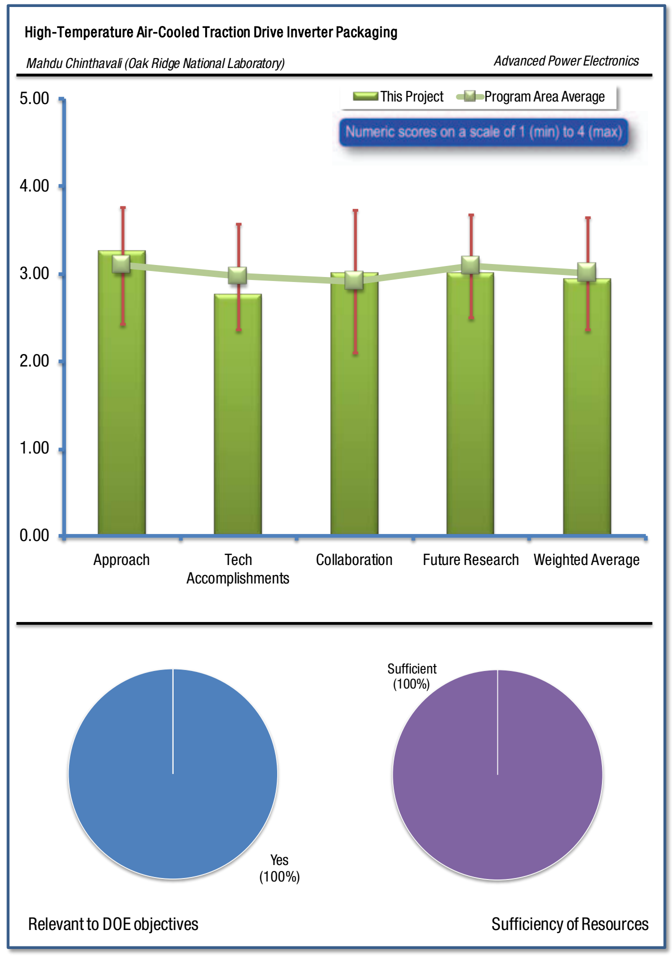
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer simply said this was a new start, while another stated that the high rating is due to the approach of building prototypes early on, becoming progressively more representative of the desired propulsion system. A third reviewer said that second generation planned to build upon lesson learned from prototype 1 is the way to go. However, this reviewer added, there's not a lot of proposal on research concerning power switches to deal with thermal constraints. The final reviewer suggested targeting a 55 kW IMMD that will meet the specs instead of targeting a 10 kW IMMD for legacy reasons. This reviewer added that it is not clear what the plans are for the motor, including the number of phases and machine topology.

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

No comments were received for this section.

High-Temperature Air-Cooled Traction Drive Inverter Packaging: Mahdu Chinthavali (Oak Ridge National Laboratory)



REVIEWER SAMPLE SIZE

This project had a total of 4 reviewers.

QUESTION 1: DOES THIS PROJECT SUPPORT THE OVERALL DOE OBJECTIVE OF PETROLEUM DISPLACEMENT? WHY OR WHY NOT?

The first reviewer indicated this supports the goals for DOE cost, while another noted the need to understand if air cooling can be reliably used to reduce power electronics cost. A third reviewer commented that low-cost inverters will help to drive the EDV market. The final reviewer stated that packaging of the power converter is always an important issue in HEV/PHEV. This research deals with the packaging that uses air cooling. It will help achieve meaningful results that can help reduce cost and increase reliability in these systems.

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 approach is excellent, while another said it would be useful to see concepts of an air-cooled power stage that can illustrate how the heat is removed and the cooling is presented to the power stage. The final reviewer said this project was re-scoped to develop an understanding of the requirements and boundary conditions for air cooling of a traction drive. This reviewer added that there is not enough information yet to evaluate the approach.

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

The first reviewer said there have been some preliminary results, while another added that so far there has been good progress made to understand air cooling. It seems that a general model is difficult to achieve devoid of specific design details. The final reviewer said new start and referenced comments above. This reviewer noted the team did not mention high temperature interconnects as a gap; is there a commercial die attach process for a 275^{o}C junction temperature device?

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

One reviewer said it is not clear what modeling is performed at ORNL and what is performed at NREL. It seems that most of the thermal modeling should be conducted at NREL given their expertise. Another said the work is mainly performed by the collaborators, adding that the PI is a program manager. The final reviewer asked if the team has suppliers of these high temperature devices that are willing to work with them.

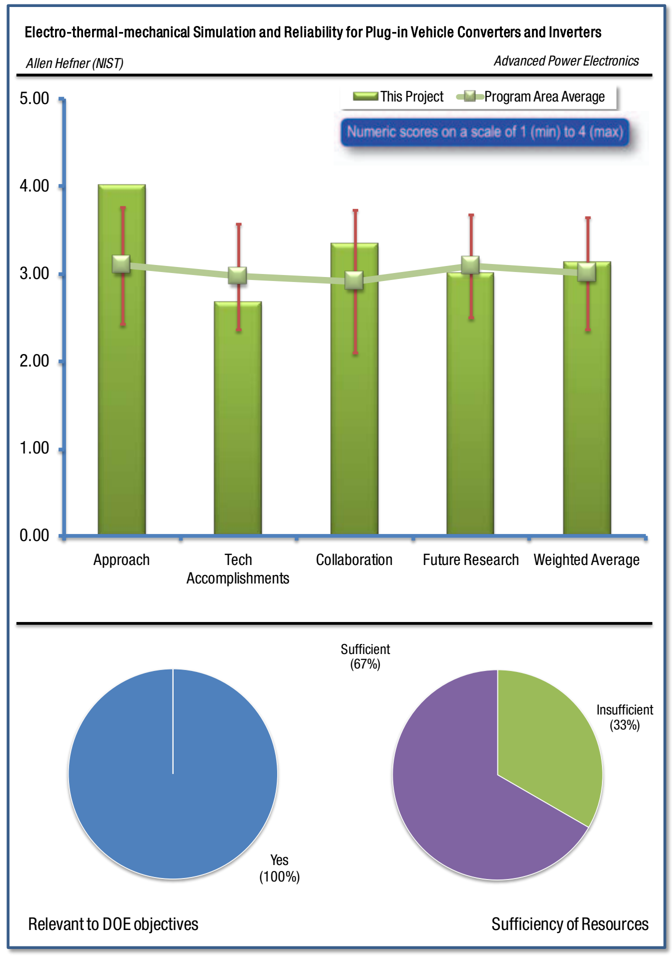
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

One commenter said the future research topics are appropriate. Another reviewer asked if the exit criteria are that, if the models from NREL show it's not feasible, the project ends?

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

No comments were received on this aspect.

Electro-thermal-mechanical Simulation and Reliability for Plug-in Vehicle Converters and Inverters: Allen Hefner (NIST)



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said the project allows optimization of the inverter cooling system based on usage and reduces overall volume, mass, and cost, which directly supports the targets. Another indicated that the research deals with thermal issues in power converters in HEV and PHEV. It is an important subject. The final reviewer said that combining physics-based electro-thermal and reliability modules to optimize performance and reliability of power modules is of great importance for vehicle, industrial, and military systems.

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 stated the proposed approach is appropriate. Another commented that it builds on past work at NIST, but also adds the reliability modeling capability developed at the University of Maryland, applied to actual modules and validated by testing. The final reviewer stated that there is very good methodology in addressing the problem; however, it needs to be validated against a known standard or benchmark. Going after soft-switching may not be the best choice for initial focus.

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

One reviewer stated that the progress is good, while another indicated good progress for the first 1.5 years of effort. The final reviewer said that it is relatively early in the project for accomplishments.

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

The first reviewer said NIST and CALCE are pioneers in their respective areas, adding that industrial companies are supplying vehicle modules/designs for modeling/testing. Another commenter stated that the project collaborates with OEMs and suppliers as well as ORNL. It is a good approach to follow. This reviewer added that it would be also desirable to have plans for implementation in actual vehicle systems.

The final reviewer said this development is for a valuable analytical tool, but it does not have a clear customer in the end. This tool should be an enabler for system optimization; however, where this tool ends up and who is going to own it is not understood. This reviewer would like to see some longer-term plans for its development and application in one of the National Labs or have it available for industry in one form or another (work with tool supplier Synopsis to have capability added).

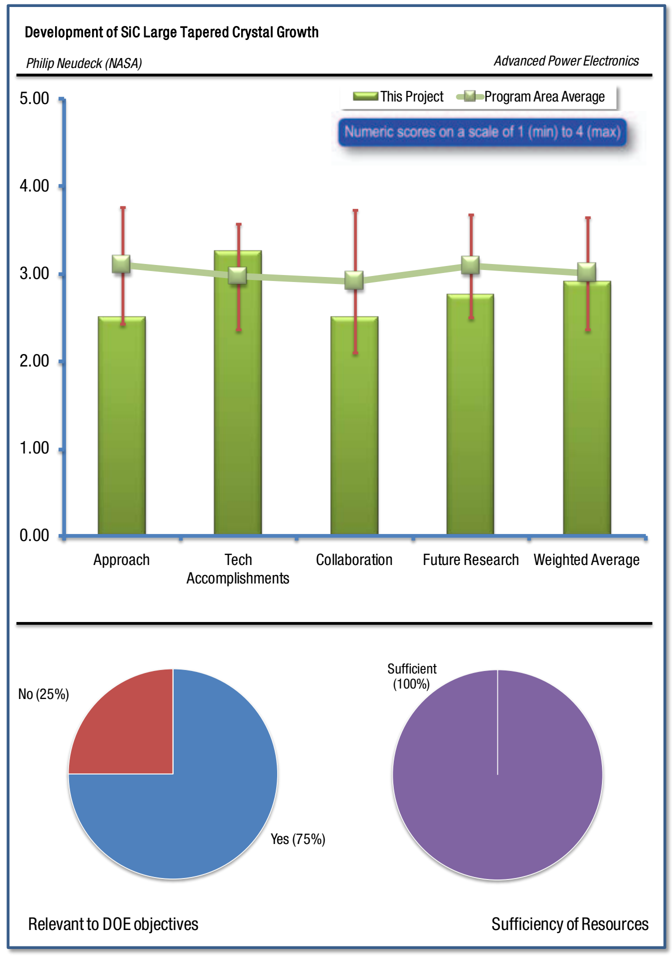
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer stated that the future research is appropriate, while another indicated that long-term plans for how this methodology will be used for future research were not well understood.

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

No comments were received for this aspect.

Development of SiC Large Tapered Crystal Growth: Philip Neudeck (NASA)



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The first reviewer said that, to the extent that this high-risk technology development actually develops into a usable product that in turn makes silicon carbide more affordable, then the answer is yes. A second reviewer said that a new SiC substrate growth method may be successfully demonstrated using the proposed novel approach, although this is a high risk project. If successful, the new SiC substrate growth approach may be scalable and manufacturable, and the new process may successfully compete with existing approaches that will also improve while the novel approach is being developed. If all of the above is successful, devices made in the new material may be suitable for vehicle applications and may lead to reduced size and weight thus reducing petroleum consumption.

A third commenter said the idea of growing a lower-defect SiC sounds “grand and big.” However, the reality is very different. There are commercial suppliers of SiC wafers which have supplied high quality SiC wafers in large quantities. These are 100 mm substrates where defect density is very low to begin with and greater than 50% yield of 10 kV, 1 cm^2 devices has been consistently shown in PiN devices. When one looks at the yield of 10 kV MOSFET devices, the average yield drops to 25-30%. Most of this drop in yield is attributed to processing induced defects (12-15 mask process) due to the lack of automated manufacturing equipment for processing 100 mm substrates. Therefore the focus should be to increase the diameter of the substrates to 150-200 mm rather than a totally un-tried new technique of crystal growth when it is clear that the defect density on the current substrates is extremely low. Increasing the diameter of the wafer with currently used and well-established techniques will lead to lower cost of the devices which is exactly what the industry needs.

The final reviewer said the efficiency benefits of silicon carbide power technology are well established. One of the primary impediments to a more rapid implementation of this technology is the concentration and types of intrinsic defects in the bulk substrate material, which act as nucleation sites for epitaxial defects and stack fault formation in bipolar devices. If successful, the proposed approach would enable the realization of very low defect density wafer material, which would have a significant impact on the reliability and performance of devices fabricated on them.

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 said this is a well-structured project with the approach clearly defined, as well as the potential barriers to implementation. The team should include more information on the characterization methods to be used in evaluating the grown material. Another reviewer said that this is about as high risk of a technology project as has ever been reviewed in the DOE VTP. As such, the approach almost defies “measuring” with the simple check-off descriptors above.

A third reviewer said that, within one decade, existing approaches to manufacturing SiC substrates for power devices have made tremendous progress, resulting in a rapidly growing SiC power diode market with rapid reduction of cost. Rapid progress has also been made in using existing SiC substrate growth approaches to produce advanced SiC power switching devices including high voltage devices with excellent performance. It is not clear that a new approach to growing SiC power devices substrates is needed, but it may be a good fall back if progress does not continue with existing approaches.

The final reviewer said that the process has been clearly divided up into the two aspects: lateral expansion of the fiber and original growth of the fiber. Both aspects are technically challenging and will require significant work before a commercially viable technique evolves. It should also be expected that a number of technically limiting problems will arise as the programs advance that may affect the overall objectives. However, that is to be expected in any new growth technique. Specific comments and questions on each aspect are listed below.

Lateral growth on a SiC fiber:

(1) Cost – more detail on aspects on the efficiency of gas deposition would help here, a typical SiC epitaxial system only utilizes a small fraction of delivered gas to grow the material – the rest flows past the deposition area and exits the system. The use of cheaper source gases than are typically used in the SiC industry may be possible, but are the desired high growth rates achievable with these lower cost gases?

(2) Parasitic depositions in the growth system – how are these avoided if the process reaches its potential to deposit many kilograms of SiC crystal. Typical epitaxial systems require maintenance after growing a few hundred grams of SiC.

(3) M-axis growth is a largely unexplored field, though significant work has come out of Japan in recent years. What problems do the authors anticipate when growing layers that are essentially 50 to 75mm thick in the different a-axis directions?

SiC fiber growth:

(1) The technology shown in the presentation material is for laser melt of sapphire; however, SiC will not melt under standard conditions. Instead it is suggested that a solvent approach can be used. Do the authors have data on what growth rates have been achieved for the solvent approach?

(2) Have low diameter rods of SiC been grown with a solvent approach, and if so, are these defect-free (except for the center screw dislocation)?

(3) Is it required that the two growth systems be linked as shown in the presentation materials. This may lead to a very complicated total growth system. Or can the thin seed crystals be grown in one system, and then the best seed crystals transferred to the lateral growth epitaxial system?

Overall this final reviewer finds the concept a fascinating one and one with great potential if the technical challenges can be overcome.

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

The first reviewer said the majority of the progress that has been made is in the design and procurements for modification/build-up of laboratory hardware needed to initiate the novel growth experiments. Another said the project has only recently received funding, adding the progress is as expected (mostly, setting up equipment to get underway on future empirical work). The final reviewer said this is a new project with little progress to date. Parts and materials ordered and system fabrication initiated.

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

The first reviewer said there is little collaboration with other organizations; it's a NASA experiment. Another commented there needs to be more clearly defined, especially with respect to detailing the contributions of collaborators. The final reviewer said that, under direct questioning, the presenter said that key crystallographic diagnostics are being outsourced to organizations recognized by the reviewer as highly competent, which is a good thing. The "when," "why," and "how" of the collaborations was not clearly expressed in the presentation, and the presenter answered the question in a way that did not clarify the details of collaborations.

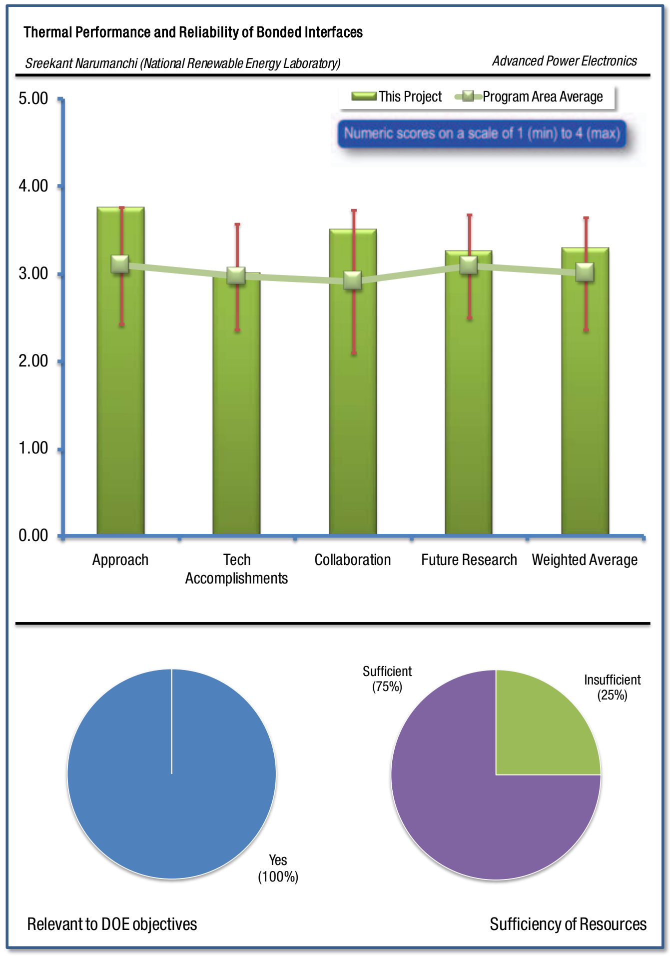
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

One reviewer said the project is well structured, although significant unknowns remain to be determined. The second reviewer said there is a big gap in going from a successful demonstration of the growth experiment to a manufacturable product that could be used to produce devices suitable for vehicle applications.

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

No comments were provided for this question.

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



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said wiring bonding is the most potential area of power electronics failure. Therefore, the research has importance. A second reviewer commented that this is a critical area of power electronics that needs detailed study. Another reviewer said that better thermal performance of inverter power stages can reduce their cost. The reduced cost can help to enable the electric drive vehicle market. A final reviewer said interfaces with improved thermal performance and reliability enables use of high temperature coolant and/or air cooling, thus enabling reduction in cost, weight and volume of power 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?

The first reviewer said the proposed approach is appropriate. Another commented that bonded interlaces are a major weak link in reliability of power packages and present a major constraint on thermal cycling application of power devices. The project is well integrated and includes all aspects (including stress, characterization, technology development, modeling and analysis, and technology transfer) needed to provide meaningful results.

A third reviewer said this is a key element of power module construction that needs this type of focus. Other areas need the same amount of attention such as interconnects, bus structures from die to inverter bus structure, and heat sinks, but these need to be done separately. One thing that needs to be included is a relative cost of each type of interface. The final reviewer said the team may want to consider adding thermal cycling for some of the parts as well as a destructive pull test to test the bond line strength at various endpoints. Also, can the team also consider using the BIM's for die attachment?

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

Comments were generally positive in this section. One reviewer said the progress is good, while another said the new start approach is good. A final reviewer said the team worked closely with the auto industry to establish the work plan. They executed the comprehensive plan to evaluate existing and advanced approaches. They also investigated new approaches consisting of sintered interfaces with silver nano-particles and thermoplastic adhesives with embedded carbon fibers.

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

The first reviewer said the collaboration is with OEM, ORNL, and others, adding that it is sufficient to carry out the tasks. Another said the team collaborates with government, industry, and academic organizations and makes good use of assets of partners in characterization, manufacturing of bonded interfaces, simulation and modeling, and application for vehicle packages. A third reviewer said working with suppliers as well as potential end users helps to focus the research. The final reviewer said the project needs more coordination. This reviewer sees some more opportunity to be better integrated into ORNL packaging work.

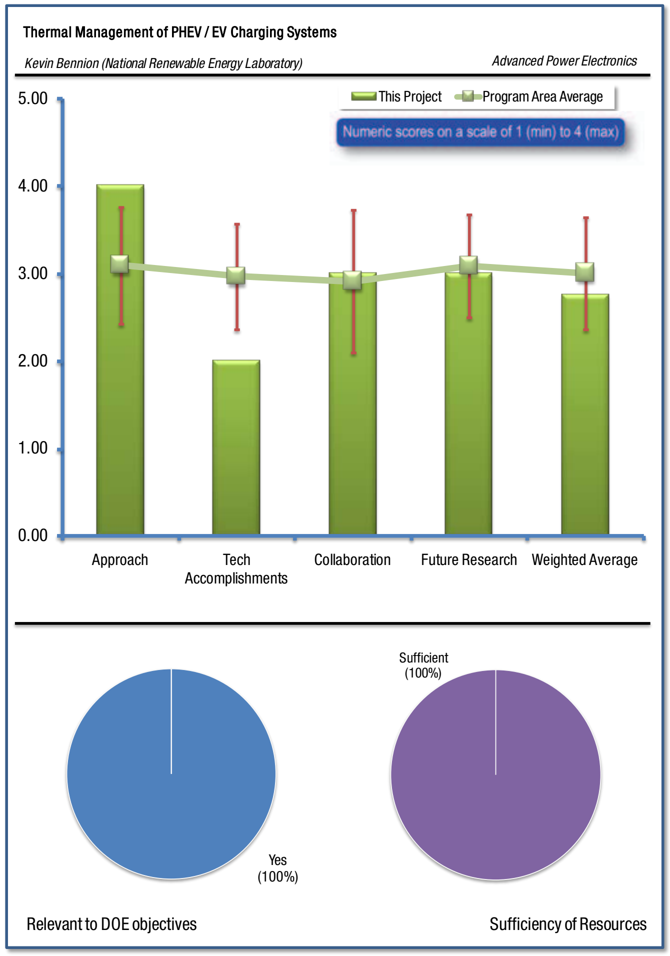
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

The first reviewer said this was a new start, while a second said the proposed future research is appropriate. A third reviewer commented the work needs to be timely for it to be relevant to industry, so the speed of work is very important. The final reviewer said the project is well planned and is focused on areas of potential high impact. This project could be expanded in funding level and could evolve into a center of excellence in advanced package bonded interface approaches for high reliability packages necessary for electric vehicles, grid inverters, and other high priority applications. Note: this reviewer marked the resources as “Insufficient” because this project could be expanded to have even more impact, not because the goals are not being met as is.

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

No comments were provided for this question.

Thermal Management of PHEV / EV Charging Systems: Kevin Bennion (National Renewable Energy Laboratory)



Reviewer Sample Size

This project had a total of 1 reviewer.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The reviewer stated that this supports the DOE goals of cost and mass.

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 reviewer stated that chargers are often an afterthought, and this project addresses the thermal issues involved. This looks to be a solid attempt to understand where the charger should reside and how to handle the heat load. This is a real issue since an onboard charger will require cooling that will have to come from the vehicle which is not running.

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

The reviewer said that so far this is a new project and there are no accomplishments.

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

There were no comments.

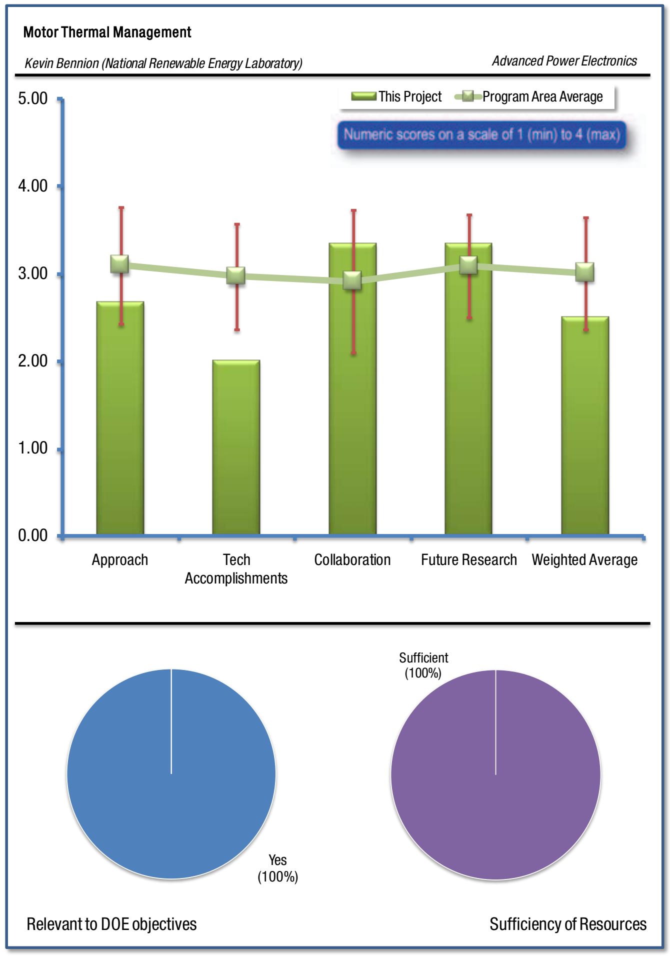
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

There were no comments.

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

There were no comments.

Motor Thermal Management: Kevin Bennion (National Renewable Energy Laboratory)



Reviewer Sample Size

This project had a total of 3 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments were generally positive in this section. The first reviewer said that motor thermal control is a key enabler to achieving high power density. Another commented that higher coolant temperatures are desired for electric propulsion systems (from a vehicle standpoint), and improved thermal solutions help achieve that goal. This would help enable more electrification architectures. A final reviewer said that motor thermal aspect is important in HEV and PHEV. Hence it is important to understand the issues and find solutions to solve them.

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 approach is fine, while another said the novelty of the project is not clear, adding that a thorough literature review is needed to decide what can potentially be a novel cooling scheme.[1] A final reviewer said, as a new program, the detailed approach tasks have yet to be formulated. NREL has established many possible cooling technologies, and selecting and focusing on these items will be important.

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

All three reviewers stated that the project is new and either that there are not significant accomplishments yet or that technical accomplishments cannot be evaluated yet.

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

The first reviewer stated that is seems to be good but that it's too early to tell. Another noted NREL solicits input from researchers, developers, and manufacturers. Their proactive approach and persistence will help to structure useful work. The final reviewer commented that the work is being carried out with participation of a university. It is suggested that they work with more suppliers of motors, OEMs, and additional institutions who have already demonstrated expertise and experience in this area.

[1] DOE note: This is actually the main focus of the first year of this project. Instead of jumping directly into proposing a specific motor cooling scheme, DOE is currently working with the University of Wisconsin to conduct a literature survey to identify the size of the contribution of motor cooling to the overall system thermal management to determine the relative value of effort in this area, and to identify promising areas for cooling technology development.

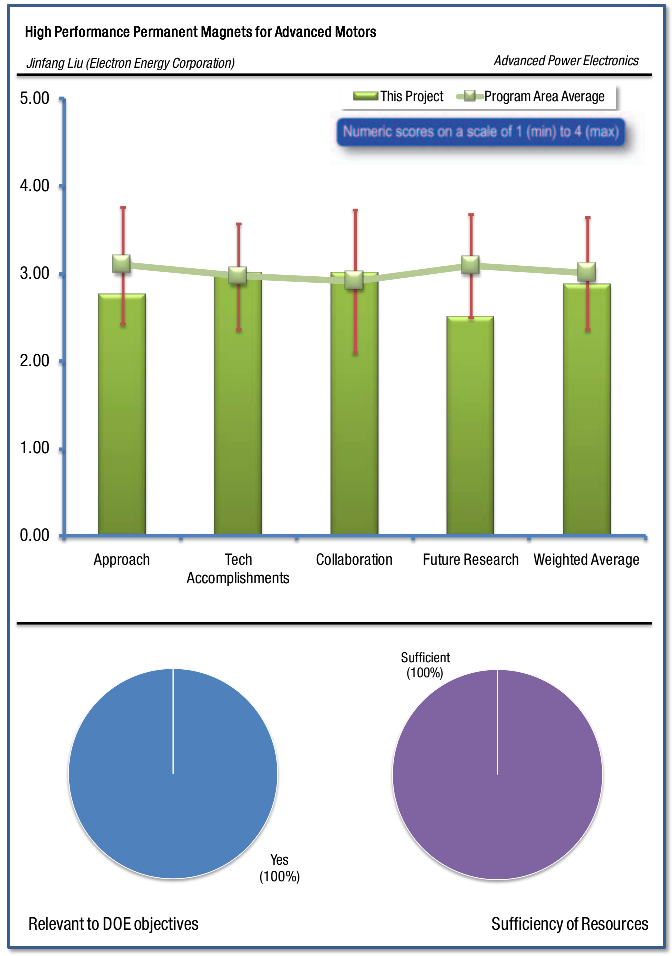
QUESTION 5: HAS THE PROJECT EFFECTIVELY PLANNED ITS FUTURE WORK IN A LOGICAL MANNER BY INCORPORATING APPROPRIATE DECISION POINTS, CONSIDERING BARRIERS TO THE REALIZATION OF THE PROPOSED TECHNOLOGY, AND, WHEN SENSIBLE, MITIGATING RISK BY PROVIDING ALTERNATE DEVELOPMENT PATHWAYS?

The first reviewer stated that the future research tasks are appropriate, while another reviewer commented that NREL is proactive and is proposing appropriate focus areas. This reviewer encourages a focus on winding cooling and encapsulation materials that remove heat from end windings effectively. This would have the highest impact in increasing the rating of electric motors. The final commenter said the proposed future work is common practice in industry when it comes to machine design, adding that novelty needs to be identified. This reviewer added that focusing on developing an accurate lumped parameter thermal model can be potentially of value in terms of speeding up the design process instead of relying on FEA.

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

No comments were provided.

High Performance Permanent Magnets for Advanced Motors: Jinfang Liu (Electron Energy Corporation)



Reviewer Sample Size

This project had a total of 4 reviewers.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

Comments in this section were mixed. The first reviewer stated that higher energy product and higher resistivity magnets help increase the motor power density and efficiency. Another reviewer said the magnet characteristics are critical on PM machine development. Improving them is always appreciated as long as it is not accompanied by a big cost penalty. A third commenter said the project addresses a major issue of today's electric machines, which is the high cost of rare-earth permanent magnets. If the project is going to be successful it could potentially accelerate the implementation of electric drive systems in the automotive industry. This would support the DOE objectives of petroleum displacement. A final reviewer stated that the project is somewhat relevant, since the program does not appear to address issues relevant to many industry participants.

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 said the technical barriers for the improvement of permanent magnet materials are addressed by the researchers. This reviewer added the focus is on the improvement of temperature stability and increase of electrical resistivity, which would enable a wider range of potential applications for permanent magnet machines. Another reviewer added that the approach seems okay, but admits to not being an expert on the subject. A third reviewer said the project is pursuing several important areas. This reviewer is, however, concerned about the focus on SmCo magnets, which are not really practical in the automotive market. The project should show that the proposed concepts are applicable to Nd magnets. Also, focusing on one or two tasks might provide better chance of success instead of spreading the project resources over several areas. The final reviewer stated that low resistivity is not a significant problem with existing magnets, aside from motors that have high stator-induced harmonics, and much of the research focuses on SmCo magnets, which are not being used by industry for vehicle electrification motors. SmCo magnets consist of expensive and price volatile materials.

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

Comments in this section were mixed. One reviewer said that some major milestones were accomplished this year: good job. Another commented that several samples of the various materials have been produced, adding that some methods are showing more promising results than others. A third reviewer stated significant progress has been made towards the goal of gradually improving the properties of permanent magnets, both for SmCo and NdFeB types. The targeted temperature range of 200-240°C seems to be higher than what the automotive industry might need for the widespread application of electric drive systems. But there might be a niche market for magnets with this temperature capability in specific applications like high speed electric compressor drives. This reviewer added that the claim of a cost reduction in the manufacturing process of magnets needs more proof. A final reviewer said the program appears to be meeting project goals, but mainly using the technologies that have the least commercial promise, and how this assists with DOE goals is unclear.

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

The first reviewer said good collaboration was observed based on the project size, while another stated that collaboration with academia and industry is occurring. Another commenter said that the collaboration with another company that is working on a DOE funded project for the development of IPM machines is important for a clear understanding of the specific requirements for permanent magnets in electric machines. The final reviewer said that having the customer's involvement is excellent, but the collaboration of the University of Delaware was not described at all.

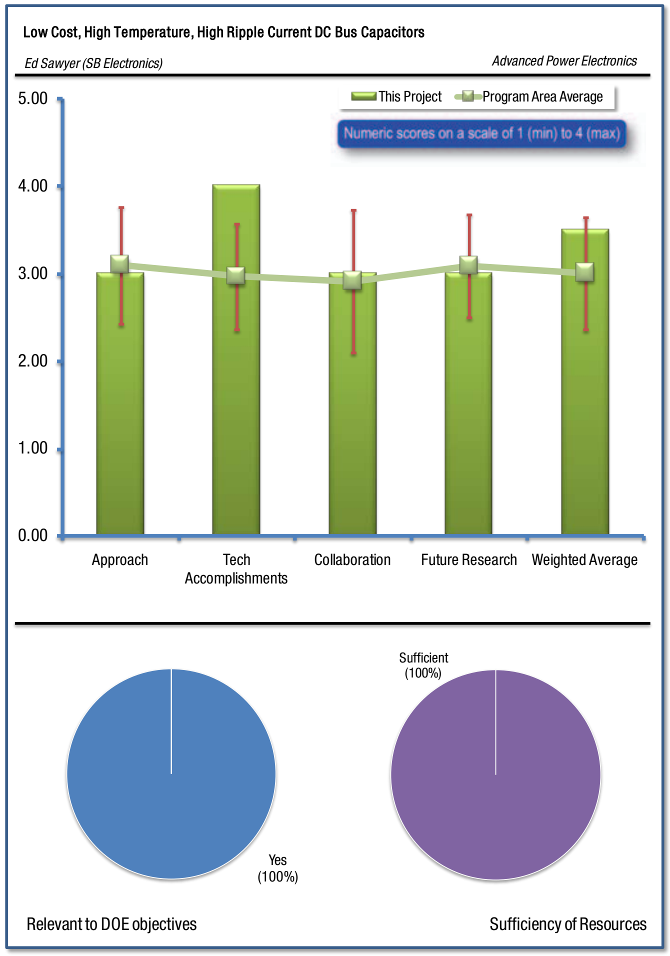
Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Comments in this section were mixed. The first reviewer stated that the DOE-funded part of the project will come to an end soon, but the researchers explained that the project will be continued as part of their own research. The proposed future work is comprehensive. Another commenter said efforts to give more maturity to the product is the right way to go for this particular project. A third reviewer noted there are several methods proposed to increase magnet resistivity. They are showing a wide range of improvement. They should be down selected to the most promising approach and this should be pursued further. This reviewer added that a cost model for estimating the magnets' cost should be developed. The final reviewer commented that the relevance of this work is questioned due to the focus on magnet resistivity and SmCo as a candidate material.

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

No comments were received.

Low Cost, High Temperature, High Ripple Current DC Bus Capacitors: Ed Sawyer (SB Electronics)



Reviewer Sample Size

This project had a total of 1 reviewer.

Question 1: Does this project support the overall DOE objective of petroleum displacement? Why or why not?

The reviewer said that high temperature / low inductance capacitors are a gap in inverter designs. SBE is trying to fill the gap to help enable the electric drive vehicle market.

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 reviewer stated that cost and temperature are still a challenge. This reviewer asked if material changes and extended life testing will address the cost and temperature challenges.

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

The reviewer said that the low inductance of the capacitor is very good. The size and the configuration of the capacitor may be a packaging concern for inverter designs. Should inverters be designed around the bulk cap or should the bulk cap be designed around the inverter? Show some examples of the latter: i.e., how to connect to a 3 phase power stage, power module, without intermediate connections.

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

The reviewer commented that the team has a capacitor, puts it in an inverter, and shows performance improvements vs. a more “traditional” bulk cap design.

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 reviewer stated that changing materials and platings may reduce cost, but the team could use an inverter partner to evaluate their capacitor.

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

No comments were received for this section.