# 3. Power Electronics & Electrical Machines Technologies

## Introduction

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 |
|---|---|---|---|---|---|---|---|
| An Active Filter Approach to the Reduction of the DC Link Capacitor | Burak Ozpineci (Oak Ridge National Laboratory (ORNL)) | 3-6 | 2.83 | 2.50 | 2.50 | 2.83 | 2.63 |
| Current Source Inverters for HEVs and FCVs | Gui-Jia Su (Oak Ridge National Laboratory (ORNL)) | 3-9 | 3.00 | 3.20 | 3.00 | 2.80 | 3.08 |
| High Temperature, High Voltage Fully Integrated Gate Driver Circuit | Laura Marlino (Oak Ridge National Laboratory (ORNL)) | 3-12 | 3.50 | 3.38 | 3.50 | 3.75 | 3.47 |
| Utilizing the Traction Drive Power Electronics System to Provide Plug-in Capability for PHEVs | Gui-Jia Su (Oak Ridge National Laboratory (ORNL)) | 3-16 | 2.75 | 3.00 | 2.25 | 3.00 | 2.84 |
| High Dielectric Constant Capacitors for Power Electronic Systems | U. Balachandran (Argonne National Laboratory (ANL)) | 3-18 | 2.67 | 3.00 | 3.67 | 3.33 | 3.04 |
| Advanced Soft Switching Inverter for Reducing Switching and Power Losses | Jason Lai (Virginia Tech) | 3-20 | 3.50 | 3.17 | 3.33 | 3.50 | 3.31 |
| Development, Test, and Demonstration of a Cost Effective, Lightweight, and Scalable | Ralph Taylor (Delphi) | 3-22 | 3.43 | 2.86 | 3.57 | 2.83 | 3.09 |
| Scalable, Low-Cost, High Performance IPM Motor for Hybrid Vehicles | Ayman El-Refaie (General Electric Global) | 3-25 | 3.00 | 3.00 | 3.00 | 2.60 | 2.95 |
| Advanced Integrated Electric Traction System | Greg Smith (General Motors Corporation) | 3-28 | 2.00 | 2.33 | 3.00 | 2.33 | 2.33 |

| Presentation Title | Principal Investigator and Organization | Page Number | Approach | Technical Accomplishments | Collaborations | Future Research | Weighted Average |
|---|---|---|---|---|---|---|---|
| **Advanced Thermal Interface Materials (TIMs) for Power Electronics** | Sreekant Narumanchi (National Renewable Energy Laboratory (NREL)) | 3-30 | 3.33 | 3.33 | 2.67 | 3.00 | 3.21 |
| **Characterization and Development of Advanced Heat Transfer Technologies** | Kenneth Kelly (National Renewable Energy Laboratory (NREL)) | 3-32 | 2.67 | 3.00 | 3.00 | 3.00 | 2.92 |
| **Air Cooling Technology for Advanced Power Electronics and Electric Machines** | Desikan Bharathan (National Renewable Energy Laboratory (NREL)) | 3-34 | 3.00 | 3.00 | 2.80 | 2.60 | 2.93 |
| **Power Electronic Thermal System Performance and Integration** | Kevin Bennion (National Renewable Energy Laboratory (NREL)) | 3-36 | 3.20 | 2.60 | 3.00 | 2.80 | 2.83 |
| **Thermal Stress and Reliability for Advanced Power Electronics and Electric Machines** | Michael O'Keefe (National Renewable Energy Laboratory (NREL)) | 3-38 | 3.60 | 3.40 | 3.20 | 3.20 | 3.40 |
| ***A New Class of Switched Reluctance Motors*** | *Tim Burress (Oak Ridge National Laboratory (ORNL))* | *3-40* | *3.00* | *2.40* | *2.20* | *3.00* | *2.60* |
| ***Benchmarking of Competitive Technologies*** | *Tim Burress (Oak Ridge National Laboratory (ORNL))* | *3-42* | *3.75* | *3.25* | *3.00* | *3.50* | *3.38* |
| ***Wide Bandgap Power Electronics*** | *Madhu Chinthavali (Oak Ridge National Laboratory (ORNL))* | *3-44* | *3.14* | *3.00* | *3.14* | *3.00* | *3.05* |
| ***High Temperature Thin Film Polymer Dielectric Based Capacitors for HEV Power Electronic Systems*** | *Shawn Dirk (Sandia National Laboratory (SNL))* | *3-46* | *3.33* | *3.00* | *2.67* | *3.00* | *3.04* |
| ***Bi-directional DC-DC Converter*** | *Abas Goodarzi (U.S. Hybrid)* | *3-49* | *2.25* | *2.50* | *1.75* | *2.75* | *2.38* |
| ***Novel Flux Coupling Machine without Permanent Magnets - U Machine*** | *John Hsu (Oak Ridge National Laboratory (ORNL))* | *3-51* | *3.25* | *3.00* | *1.50* | *2.50* | *2.81* |
| ***A Segmented Drive System with a Small DC Bus Capacitor*** | *Gui-Jia Su (Oak Ridge National Laboratory (ORNL))* | *3-53* | *2.75* | *2.50* | *2.25* | *3.00* | *2.59* |
| ***Direct Cooled Power Electronics Substrate*** | *Randy Wiles (Oak Ridge National Laboratory (ORNL))* | *3-55* | *3.17* | *3.17* | *3.17* | *2.83* | *3.13* |
| **OVERALL AVERAGE FOR PEEM** | | | **3.10** | **2.95** | **2.88** | **2.99** | **2.99** |

NOTE: Italics denote poster presentations.

## Overview of Advanced Power Electronics

**1. Was the Sub-program area adequately covered? Were important issues and challenges identified? Was progress clearly presented in comparison to the previous year?**

A reviewer stated that given this was an overview, no details were presented. It appeared to them that the outlined program met the goals. Certainly the issues raised were valid, with progress to be defined in more detail. Wrestling with size, cost, and weight issues are not new, but planned work appeared constructive. Another reviewer noted the sub-program area covers a broad area of topics that are necessary to reach the DOE goal in PHEV/HEV. One other reviewer said yes, the sub-program does an excellent job of addressing a broad set of technology needs and then connecting these efforts with the user to push development. It was not readily apparent that there is a significant pull from the users (i.e., US automakers) to obtain a gauge of their current technology with an emphasis on their current limitations. It may help to provide a comparison of the US hybrid technology to what has been observed with the foreign hybrid technology.

A reviewer stated that as a program overall APEEM is doing very well to address the issues. Another reviewer said that this was their first time attending this review. The sub-program goals were covered in appropriate depth and detail. The programmatic goals were clearly presented by the speaker and in the presentation materials. This reviewer went on to say that significant results were presented; they were able to discern relevant progress even though they have not previously attended the Program Review. One reviewer noted that the activities of the sub-program were adequately covered. The various teams seem to have a good understanding of the challenges and barriers. Based on the presentations, it seems there is a lot of progress compared to the previous year. Another reviewer stated that overall there was a great job of translating the goal of reduced dependence on oil into logical APEEM programs. Important issues were identified, and strategies were given to address them, with some contingency planning as well. Clear accomplishments were shown in power electronics, motor design, and thermal management. One reviewer noted that the full range of issues and challenges were covered by the sub-program, ranging from the development of high voltage switching devices and high temperature electronic devices for gate drives to advanced packaging, thermal management, and vehicle system integration. Progress was clearly demonstrated in all presentations. It was especially nice to have the previous year slides provided to the reviewers to gauge the current year accomplishments.

Another reviewer noted the sub-program covered all the important areas. The challenges were identified very clearly and the important issues were addressed. They were very impressed by the progress the sub-program made over the last couple of years. Two of the reviewers mentioned Susan’s presentation, with one saying the presentation was very concise and addressed the critical technological focus areas of the PEEM programs. The slides presented explicitly demonstrated progress and achievements over the previous two years. The other reviewer who mentioned Susan’s presentation went on to say the presentation provided a good overview of the Power Electronics and Electric Motor program and goals. Susan addressed key issues and challenges such as cost, power density, and materials. She also showed key accomplishments for the past year in terms of CSI, IPM and integration which demonstrated good progress toward system goals. There were two other reviewers who said yes, with one saying yes to all of the questions, and the other reviewer who said the objectives and rational were adequately covered and progress was alluded to, but they didn’t see a cogent, easy to understand, description of relative progress.

**2. Are plans identified for addressing issues and challenges? Are there gaps in the project portfolio?**

A reviewer stated that the number one gap to be addressed is the cost reduction necessary in electric drives; more could be done in this area. Another reviewer noted that the plans were well thought out. They include multiple development directions in high risk areas (e.g., developing PM and non-PM motors, considering the risk of PM availability and price escalation). This multi-pronged approach avoids putting “all the eggs in one basket”. This reviewer went on to say that some of the gaps that they are concerned about have to do with problem definition and target metrics in electric machine development. Currently, the focus is on motor power density, with the assumption that a gear box will provide the necessary output torque to drive the vehicle. However, torque is a better indicator of motor volume, not power. Driving to higher power density levels without constraining torque will drive cost into the mechanical drive train (gears, bearings, clutches, etc). In the worst case, it could result in a drive train that is impractical to manufacture, making commercialization unlikely. Also, it may make sense to add the gear train cost into the $/kW or $/N-m objective. This would capture the total cost impact to the consumer, and would avoid the "squeezing the balloon" effect of sub optimization. Another thing this reviewer said was they think that any motor development should have a torque ripple constraint, if it is to be used in automotive markets. Without this constraint, there are many motor technologies that would be attractive for reaching DOE goals for cost (like switched-reluctance), that would probably have too much audible noise for market acceptance in hybrid cars. This should be built into the project from the beginning, and not become an afterthought. Finally, this reviewer stated that the motor development problem definition starts with the assumption that the motor uses 105 C WEG cooling. However, they don't think this is consistent with achieving the highest power or torque density. Spray oil cooling (usually 90-100 C maximum oil temperature in today's transmissions) generally provides more effective heat transfer. In particular, it is significantly better in getting heat out of the rotor, which is essential for induction motors, to avoid bearing damage. Also, with the DOE's drive for higher speed machines, it is likely that oil will have to be pumped to the motor bearings anyway, so why not use it to cool the machine? Another reviewer noted that the plans identified for addressing the issues and challenges are overall good. There are some gaps. There should be more projects on component and subsystem reliability.

A reviewer stated the program appears to be robust and aggressive; it addresses the greatest technical challenges. They can think of no significant gaps. Another reviewer said they believe the project portfolio covered all the necessary technical areas. Most of the projects have good plans and path forward in terms of addressing the issues and challenges. Six other reviewers all stated the plans for addressing the issues and challenges were identified and there were no gaps. One of the six reviewers also commented that an important advantage was recognizing that technological advances and materials sourcing issues require changing research direction. This is important to avoiding investigatory dead ends…with resulting people and funds misdirected. Another of the six reviewers added that what they saw looked like something that was consistent with a long-term philosophy that might be getting a little dated. Is the program keeping pace with events? Comments from another one of the six reviewers added that the plans for addressing issues and challenges were identified in both the introductory address and the individual presentations. Each presentation clearly presented the current challenges and the plans for addressing them. While some programs could be wider in scope, there are no gaps in the overall program portfolio. The last of the six reviewers added there were no details shown due to the limited time.

A reviewer stated that most of the focus in this category was focused on motor technology considerations with respect to PM versus induction machines, permanent magnet materials availability and associated costs. Adequate focus appears to be placed on the traction drive subsystem (inverter, converter power electronics). Another reviewer commented that there may be a need to increase the efforts in developing high temperature, high energy density dielectric materials with an emphasis on improving the capability to scale-up the technology to the industrial scale. It would help to gain an understanding of commercially available capacitor technology, current capacitor R&D, and the common barriers to technology development. This reviewer went on to say there are a few efforts focused on reducing the requirements for the DC-link capacitor, but it was unclear as to how this would affect the capacitor (i.e., new requirements?) or whether this approach led to a lower cost and higher performance. The packaging of the capacitor was not addressed, is that of concern? One other reviewer stated that the issues are well addressed. As thermal control improves, higher current densities will be power in power inverters. These challenges will need to be quantified. How much current can the silicon handle under varying conditions as thermal systems become capable of dissipating up to 400 watts/cm$^2$? This reviewer went on to say that documenting the performance of state of the art PEEM systems is very useful. It would be even more useful if the concepts presented show the projected end of life performance along with the initial performance.

**3. Does the Sub-program area appear to be focused, well-managed, and effective in addressing the DOE Vehicle Technologies Program R&D needs?**

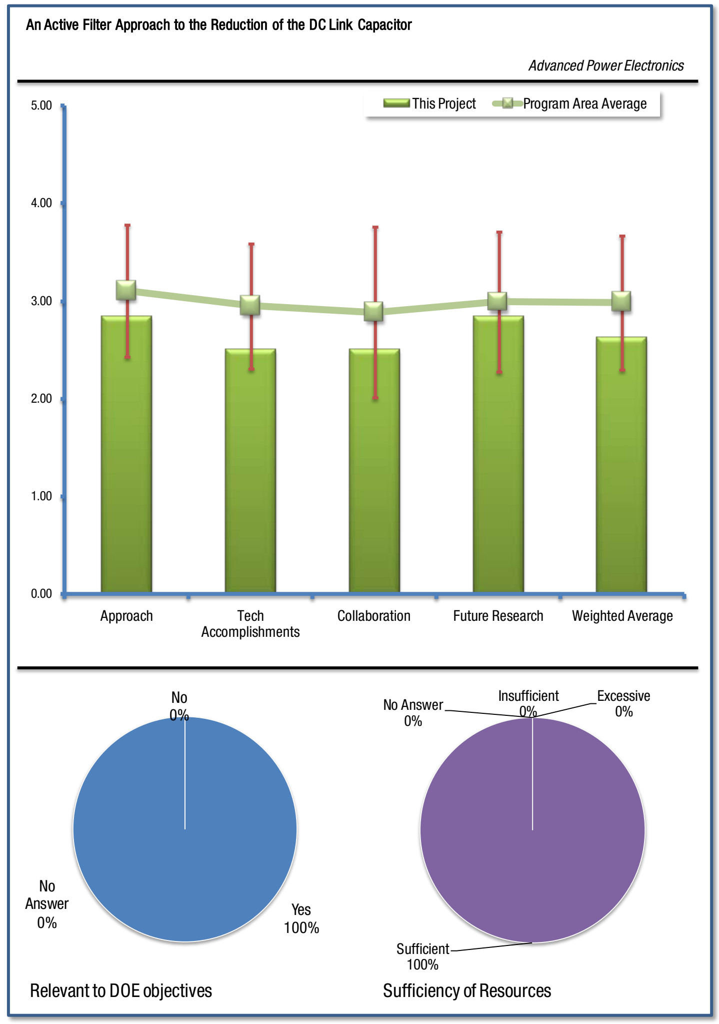
A reviewer stated that APEEM has a good focus going forward. Another reviewer commented the program has identified clear and relevant goals. It appears to be focused and well managed. There are significant technical results. The program appears to be open to changing technical needs. It also appears to be capable of responding to changing political/technology priorities. Comments from another reviewer said yes, the program is focused and well-managed. There is a good portfolio of projects as well as a challenging set of goals that should ultimately meet the DOE VTP R&D needs. One reviewer stated that overall, the program looks well-managed. The accomplishments to date show a productive track record, and justify continued spending and resources in these areas. They are very impressed with the whole program. Another reviewer shared that the sub-program appears focused and well managed in terms of addressing FreedomCAR challenges, but there is a lack of understanding on how the program compares to the domestic state-of-the-art in Electric or Hybrid Electric Vehicles. A reviewer stated the sub-program is extremely well focused, well-managed, and effective in addressing the R&D needs. The sub-program is very efficient in generating results with the current funding, and, as it contains some of the most critical technologies to advancing the DOE VTP, it could have even more impact if more resources could be allocated to this area. One reviewer said that it is focused, well managed and effective. The ultimate test is if one or more of these technologies, or concepts, makes it to a commercial product. There were four reviewers, who answered yes, with one adding the program is well managed and making excellent progress, there is a lot of good R&D projects within APEEM. One other reviewer who answered yes added there is a good focus on developing of fundamental understanding of the technical challenges and then focusing on developing the technology for targeted applications.

A reviewer stated that as an overview of the PEEM program, it was seen as directly related to the goal of making practical cars that can travel some distance on battery power available at a price comparable to current ICE-only models. Another reviewer said the sub-program is focused, well managed and effective. However, there are some repetitions of work (air-cooling) that need to be evaluated for usefulness. Projects need to address the cost issue more concretely.

**4. Other comments:**

A reviewer stated the focus on the reduction of cost may be addressed by having more projects that work with additional suppliers. The structure of USABC may provide a good template. Another reviewer said it was a very useful and informative review. Another reviewer commented there was a great job of working with industry (both OEM's and component suppliers) and university resources. Comments from another reviewer read while non-domestic vehicles were described and compared to FreedomCAR goals, there was no description or status of domestic vehicle makes. The variation in the funding for individual programs is significant (1-10x) but the presentations are essentially the same in depth. It seems that large programs (>$10M) should have more extensive review presentations. Also it seems that some of the reviews should be limited to 'government only' in order to assess the performance of the contractors. One reviewer noted that it was way too much information presented on each slide, and it was very hard to follow. Another reviewer stated this was a nice summary. The comments from the last reviewer suggest diversifying the program participation to include more university and small businesses in the program.

## An Active Filter Approach to the Reduction of the DC Link Capacitor: Burak Ozpineci (Oak Ridge National Laboratory (ORNL))




**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?**

One reviewer referenced the importance of reducing the size of the DC link capacitor. Another observed that while the capacitor size will be reduced, overall cost may not decrease. A third reviewer noted that the project is aimed at improving the inverter design, and a fourth explained that the ultimate goals of the project are to reduce mass, volume, and power requirements versus the Toyota Camry standard. Yet another reviewer stated that in trying to help reduce the size of the DC link capacitor, the project seeks to come up with a more compact power converter that will accelerate the market penetration of HEVs, PHEVs, and EVs. A final reviewer commented that the project is a good approach to decreasing the size and weight of the system while simultaneously increasing the efficiency. This reviewer pointed out that the effort also will establish a baseline to determine the benefit of balancing between using a capacitor versus using power electronics that operate at a higher switch rate, yet he expressed concern over the cost of the active filter with respect to the DC link capacitor it is replacing. There are potential high temperature capacitors (up to 200°C) that could be developed but, according to this reviewer, the development efforts are limited due to their higher cost and lack of current commercial demand.

**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?**

In response to this question, one reviewer identified significant issues with additional switching losses imposed by additional switches, including the type of fuel economy impact that may result and the lack of clarity on whether the space-saving achieved through the smaller capacitor is taken up by additional circuitry and cooling needed to ensure long term reliability. Several reviewers pointed out that cost trade-offs are not analyzed, with one adding that power loss is very speculative. According to another reviewer, the investigator presents a robust approach in which the opportunity to reduce system power losses through both improved component hardware and improved control algorithms has been defined. Still another reviewer explained that the weaknesses have been well described by the authors, and that the approach, even with the promised improvements, will trade off the capability to operate at higher temperatures and a smaller capacitor for higher losses. The inverter efficiency is a key to the success of hybrid and fuel cell technology and cannot be lowered significantly.

One reviewer observed that the proposed use of active filters to reduce the size of the DC link is not a new idea; the key novelty is in the control sachem to help reduce the losses in the active filter. This reviewer opined that the following should be done: (1) undertake a high-level comparison of cost and reliability of the proposed system (with the active filter) versus the baseline case (with only the DC link capacitor) to determine whether the proposed system offers a net gain without significant cost and/or reliability penalties; (2) prepare a clear summary of how the proposed method compares to what already exists in the literature; (3) exercise more caution vis-à-vis the claims of improvement over the Camry, especially since the project is still at the simulation stage and, as it moves toward building prototypes, the expected benefits will start eroding; and (4) the improved APF might reduce some of the benefits of eventually migrating to SiC devices due to the lower switching frequency, but SiC devices still offer high temperature advantages.

One reviewer thinks it would help to establish, with respect to capacitance, temperature, current carrying capability, frequency, and failure mode, what capacitor is available now for the active filter. It appears at this time that a ceramic capacitor could be used to demonstrate the concept of the active filter approach; if this baseline is established, it would enable capacitor R&D efforts to design the device to the requirements.

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

One reviewer feels many questions are still left unanswered, and another believes there are still some significant challenges and risks that need to be retired. Even with the improved APF, a 500 microfarad capacitor is still relatively large, and the losses, albeit reduced (based on simulations), remain a key challenge. There is a need to move faster toward some hardware verification of the simulation results. Yet another reviewer observed that to date, the project has been a simulation exercise. Project completion is scheduled for September 2009, but only 50% has been completed thus far.

On the other hand, another reviewer thinks the program clearly is making good progress in the simulation and control algorithm tasks. This reviewer added that the schedule calls for hardware development of the 55 kW inverter in the summer of 2009, and he assumes there will be some sort of experimental validation of the simulation efforts. This individual expressed concern that this portion of the effort is somewhat compressed, but he acknowledged that the details of the relative importance of this task in the overall project plan were not discussed during the presentation. Still another reviewer believes that much progress has been made towards establishing an initial circuit design and simulation capability that identified the active filter's potential, and that good progress is being made towards developing an understanding of the variables that can be controlled to optimize the system, with a proper balance between capacitor size, switch rate, and efficiency. This reviewer expressed the view that it would be beneficial to show the amount of ripple current in the capacitor given the indication that it is lower when using the active filter, and he added that inasmuch as the capacitor size is decreased significantly, it would be of concern if there is a notable increase in current per volume (may necessitate a thicker electrode, which will limit the graceful failure of the capacitor). This reviewer also queried how this approach affects the transients and whether the reduced capacitor size has an effect.

One person pointed out that at the last review, the large amount of additional losses was identified. While a new control scheme has been proposed, the improvement in the loss has not been quantified.

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

Of the reviewers that commented, one remarked that it was not readily apparent from the presentation that a strong collaboration exists. A second noted that the presentation identified collaboration with the University of Tennessee, and that the university's tasks appear to be appropriate for its capabilities. A third reviewer stated that it might be a good idea to have an industrial partner to provide some insights about what actually has been built and tested, as well as some guidance about packaging and thermal management, which are critical to achieving the overall size reduction.

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

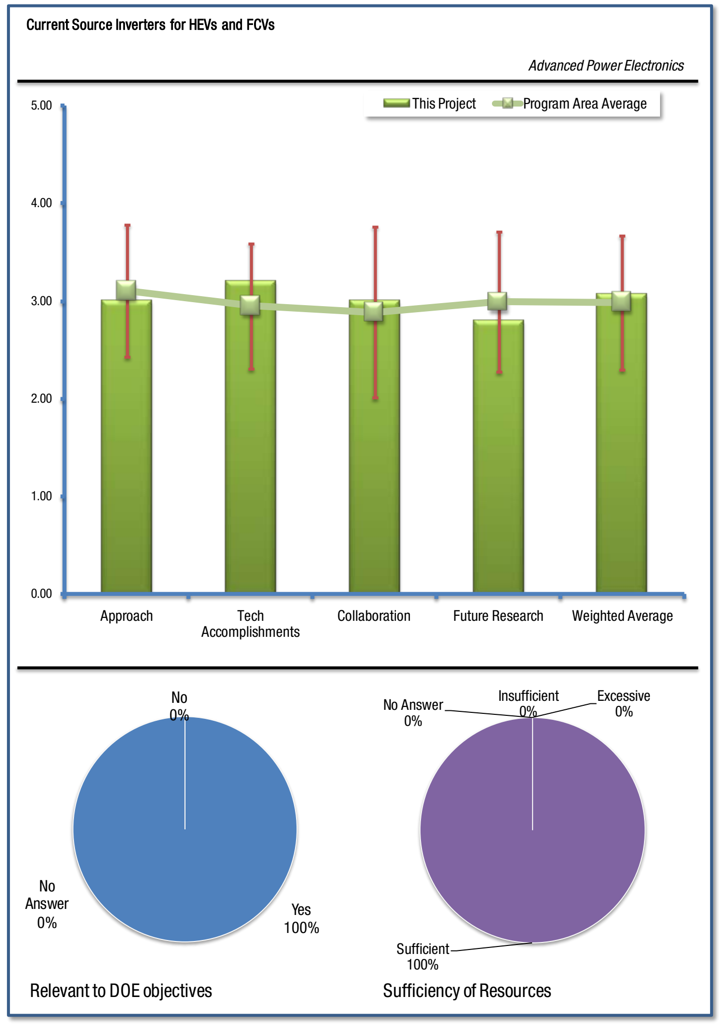
One reviewer noted that the project has no FY 2010 request, but added that the presentation clearly identified specific goals for future work. Another reviewer commented that the project's weaknesses have been identified. Still another stated that the amount of work proposed for FY 2009, including exploring new topologies and building and testing a prototype, seems to be very aggressive and there might be a need for re-scoping. In addition, in this reviewer's opinion, there is a need to move faster towards some hardware verification of the simulation results.

Still another reviewer opined that the project identified a good approach for investigating the advantages and limitations of the active filter as the size of the components and switch rate are modified. This reviewer added that it will help to construct the hardware and obtain real-time data to compare with the simulation. Finally, one reviewer believes there is a need to understand the progress made to date versus the original goals and gauge just how far the project has moved the needle.

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

All of the reviewers think the resources are sufficient.

## Current Source Inverters for HEVs and FCVs: Gui-Jia Su (Oak Ridge National Laboratory (ORNL))




### 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?

Another reviewer observed that inverters are a significant contributor to the initial HEV system cost and impact fuel savings directly, through their own efficiency, as well as indirectly, through their effect on electric machine efficiency. The reviewer continued that this inverter technology provides clear advantages over the current technology, both in terms of initial system cost and operating cost (system efficiency). The inverter cost itself is reduced, and its higher temperature rating, if achieved, will eliminate the need for an extra cooling loop, further reducing the system cost.

Pointing out that EVs and PHEVs are important approaches to meeting DOE's petroleum reduction goals, another reviewer explained that the capacitor of the electric motor inverter is a significant portion of the cost and volume of the conventional VSI inverter, and the proposed CSI inverter approach reduces the capacitor needs. Consequently, this project may aid in meeting DOE cost and volume goals. Moreover, the reduced waveform distortion of VSI may improve motor lifetime.

According to another reviewer, the goal of demonstrating a current source inverter for EVs is important because the topology must displace well understood Voltage Source Converter topologies. Current source topologies are well matched to EV requirements due to the battery or fuel cell source and the natural boost properties for driving motors at high voltage to reduce $I^2R$ losses and reduce motor size.

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

Responses to this question were mixed. One reviewer explained that the project has a logical breakdown and tackles one major problem at a time. Another praised the project's approach as very good and stated that the use of reverse blocking IGBTs will make a significant impact. This same reviewer added that the current approach of using IGBTs and series diodes custom modules is good, but noted that the series diode loss is not insignificant. He further added that several things were not adequately described, including open-circuit control and the use of normally on reverse blocking GaN switches. In addition, while the use of an interface circuit to allow regenerative battery charging and low output voltage appears to be a good idea, as was the case at the November 2008 kick-off meeting, no details were provided. To determine the feasibility of the approach, details should be made available.

A different reviewer raised concerns about the battery current waveform quality (i.e., ripple) in some operating conditions, and indicated that while these concerns have been expressed to the investigator, they have been answered only in part. This reviewer also said that the cost, losses, and complexity of the auxiliary circuit seem to have been understated, and that the availability of reverse blocking fast switching devices is a hurdle.

According to the third reviewer, the investigators have made progress in the prototype and testing, but the work does not explicitly demonstrate that a CSI is superior to a VSI. The prototype, though, does show why and how the high temperature operation can be reached from the systems perspective.

Another reviewer observed that high temperature inverter operation reduces the cost, volume, and weight of the inverter coolant system but requires high temperature components. High temperature, he added, is a challenge for the VSI capacitor because voltage is derated with temperature, although the reduced capacitor requirements associated with the CSI approach (2000 µf to 200 µF) mitigate this challenge. In addition, the CSI approach has no anti-parallel diode requirement but requires a reverse blocking switch. This same reviewer then pointed out that the reduced capacitor requirements of the CSI approach may be offset by increased output filter capacitance requirements; that the efficiency is only 97%, although a 3x voltage boost may help the efficiency of the motor; and that VSI fault response is well understood using switch desaturation protection by turn off, but CSI needs to turn on switches for short circuit condition - this needs to be tested.

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

One reviewer responded that the CSI charging detail is unclear. A second reviewer stated that the experimental results confirmed the simulation of design for the low temperature cooling phase. This reviewer added, though, that it would have been good to hear more about the projected cost and measured efficiency (series diode and IGBT vs. IGBT with a dual voltage blocking option), and that while the focus naturally was on the inverter, there seem to be efficiency advantages for the electric machine as well (e.g., voltage boost, possible harmonic reduction). On the latter point, he suggested possibly tying in a machine designer's view of how these advantages translate into initial and operating cost reduction for the electric machine.

According to another reviewer, the investigator met the milestones and the go/no go metrics. Good progress has been made, and he described the 97% efficiency as good. One person remarked that the investigator is making an effort to address the main hurdles, but that some lay outside the project's scope (i.e., availability of suitable power devices).

The final reviewer cited the following as the project's FY 2008 accomplishments: demonstrated prototype; lowered capacitance by 10x; low THD; and low volume. He then cited as an FY 2009 accomplishment the fabrication of the prototype for operation with a 105°C coolant. This reviewer added that reverse blocking IGBT is required, so the project worked with Powerex to obtain custom 1200V, 400 A modules. Noting that Fuji also has modules under development, this reviewer stated that the cost of the custom/niche reverse blocking IGBT approach merited discussion relative to conventional IGBTs used in the VSI approach. (This is not a technical challenge, but the lower volume of reverse blocking devices may increase the cost. Other high-volume applications do not need reverse blocking.)

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

According to one person, there was no indication of with whom the project is collaborating and the progress level. Another reviewer, however, commented that the project leveraged component manufacturers' expertise to address IGBT development barriers/opportunities, while a third stated that the project appears to be interfacing with the thermal control group. A fourth reviewer observed that the project is working with Powerex to develop custom reverse blocking IGBT modules. This reviewer noted, though, that the presentation did not discuss plans for testing the inverter with motor or vehicle integration issues, adding that these should be discussed in FY 2010 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?**

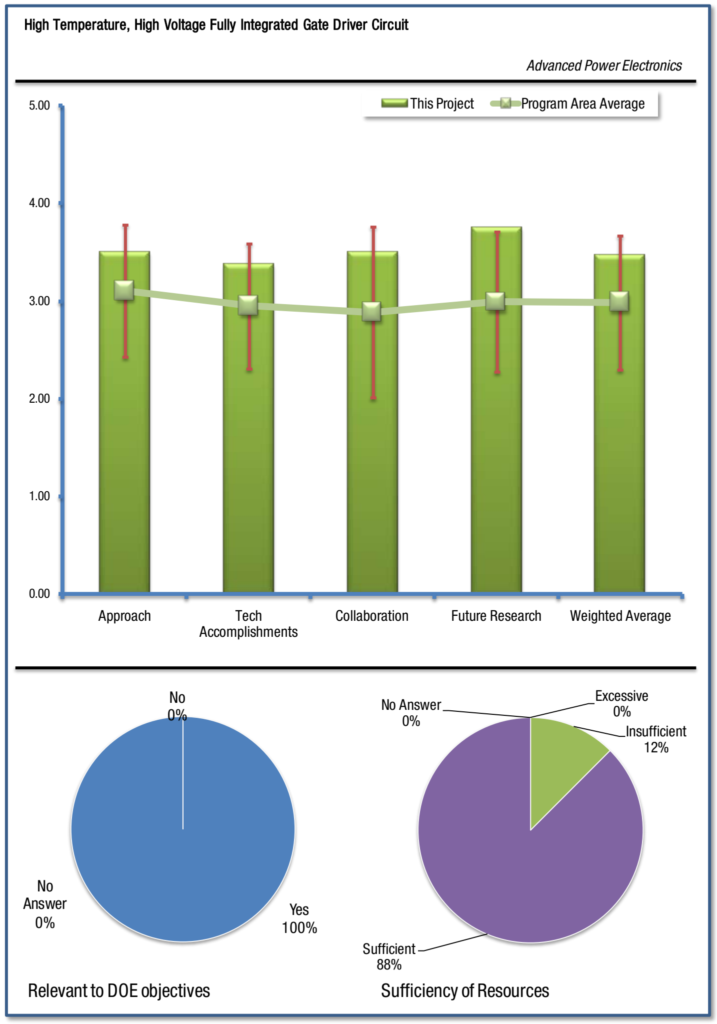
One reviewer described the proposed future research as very good, although he noted that many details remain to be divulged and he further observed that infusion of reverse-blocking IGBTs will be the key to reducing losses in series connected reverse blocking diodes. A second reviewer explained that the prototype build will show the results of the concept. Another reviewer stated that the series diode/IGBT approach can be used as an alternative to dual blocking IGBT. The project's strategy for dealing with the temperature limits of output capacitors is not clear; it seems merely to have shifted the temperature rating problem in current systems with a DC link capacitor.

A fourth reviewer stated the project is 08-2010. For the remainder of FY 2009, the goal is to complete the design and development of the 105°C version, which seems to be on track for completion. For FY 2010, the presentation proposed to test the 105°C system with the latest capacitor and switch components and study the applicability of the CSI approach for other vehicle applications. This, according to the reviewer, has merit and would provide a complete result for the project. It should include a critical evaluation of the realistic prospects of the CSI approach compared to VSI, including a comprehensive analysis of the pros and cons of both approaches. This reviewer noted that the presentation also discussed SiC and GaN for future, but the benefits of the CSI approach for normally off SiC are not as great as when normally on SiC was the only SiC option; CSI may lose some interest as SiC devices with normally off capability emerge.

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

All of the reviewers expressed the view that the resources are sufficient.

## High Temperature, High Voltage Fully Integrated Gate Driver Circuit: Laura Marlino (Oak Ridge National Laboratory (ORNL))




**Reviewer Sample Size**

This project had a total of 8 reviewers.

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

According to one reviewer, because the ability to integrate the gate drive/control within or in close proximity to a power module is vital for highly integrated modules, this project plays a key role in enabling high temperature inverters in HEV and PHEV applications. The reduced cooling requirements associated with these products would enable greater market penetration of HEV and PHEVs, and a higher level of HEV and PHEV adoption by consumers will enable petroleum displacement and associated greenhouse gas reductions.

Another reviewer noted that it helps the SiC solution to have a driver that meets the same temperature requirement, while a third observed that integrated gate drive can also help cost reduction, and that specialty gate drives for new devices are essential and typically are not available on the market. A fourth reviewer posited that if high-temperature power modules are going to be used, then high-temperature gate drives probably are necessary to control them. Still another reviewer commented that high temperature device drivers will improve the performance and efficiency of electric traction and power electronics, which will decrease fuel usage.

One reviewer explained that the project's success would allow a single, to-be-well-characterized component that can drive traditional silicon or high temperature semiconductor switches (as known at present) without extensive qualification testing. When completed and debugged, this part would reduce design risk. This reviewer went on to state that the project supports petroleum replacement by reducing inverter design time, with that contribution assisting in the reduction of EVs' time to reach the market and improving inverter reliability in the field.

Yet another reviewer expressed the view that the development of a high temperature gate driver that can be used for controlling SiC and GaN switches supports the overall DOE objective of petroleum displacement in two ways. First, enabling the use of SiC and GaN switches supports the development of high voltage, high performance power electronics, which will reduce the weight of the power electronics through wire minimization and reduce the load on the battery, thereby improving the cost and reliability of multiple EV platforms. Second, enabling the gate driver to operate at high temperature permits its use with the desired 105°C coolant temperature that allows for minimization of cooling system weight and 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?**

Responses to this query were generally positive. In one reviewer's opinion, the approach is solid and appears to be on track to overcome the technical barriers associated with high temperature drive circuits. Another reviewer, observing that the work is focused on a third generation driver with improved features, described the overall approach as excellent. This reviewer stated that it looks like it will operate up to 200°C, which is unheard of. The investigators are addressing all technical barriers and have excellent working partners. The biggest problem is finding devices to drive; there are not many SiC and GaN switches around.

According to another reviewer, the work has considered practical design aspects such as different voltage ranges, protection, on-board power supply, etc. It also is considering driving capability to suit different devices. The SOI approach allows high temperature environment operation. Design of custom IC is essential for cost reduction. A different reviewer stated that the technical approach is consistent with the larger issue of compatibility with practical commercialization considerations. The design is being implemented on an SOI foundry technology supported by a reputable commercial foundry. This is one of the most important factors to making the research relevant to the automotive industry, and the selection of Ben Blalock to deliver this is a wise choice.

One reviewer explained that the focus on the development of a high voltage, wide temperature range capable SOI gate drive chip places sharp emphasis on a key barrier to the development of a 105°C coolant EV, HEV, or PHEV. It addresses the barriers of reducing volume and weight, providing higher temperature tolerance and reducing cooling needs. The approach includes a number of important features directed at improving the reliability of the gate driver as well, including improved circuit topology and incorporating protection features. The selection of SOI is wise, as it provides more than enough high temperature capability (low leakage current, latch-up immunity) at a reasonable cost and proven reliability. In this reviewer's estimation, the only element lacking is some consideration of the ability of the packaging elements of the gate drive also to stand up to the temperature, including the issues of board and metallization, high temperature passive components, and high temperature solders.

A final reviewer cautioned that care should be exercised with the "one size fits all" concept. Sometimes those approaches *will* fit all, but not as neatly or as cleanly as would an application-specific design. This reviewer added that the silicon on insulator approach to enable high temperature operation is the key to the project's success.

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

Among the several positive comments, one reviewer praised the excellent project progress, adding that the device is very well designed and has been demonstrated to perform well even at temperatures (200°C) in excess of those needed for this application. The additional protection circuitry to turn the device off in the event of load short circuit, over temperature, and under voltage also is very impressive. In sum, all indications are that the program is well on the way to meeting its objectives.

Another reviewer described the progress to date as good. In this person's view, there is some risk associated with the loss of the SOI vendor, but this is likely to be manageable for the duration of the project, and if the project is successful it probably would not be a barrier to volume production. A third reviewer commented that the project has made significant progress in the design of this driver. The investigators are adding features such as desat and selectable gate resistance, which will be beneficial towards making a universal gate drive.

According to one person, while the progress is good, the design is not going to be ready for manufacturing for many years. A different reviewer noted with respect to the design issues that they can be addressed successfully. Yet another reviewer stated that some tests have been performed with existing gate drives, and observed that the group is getting familiar with the real life device operation. The boost-strap gate drive IC is under design. However, the circuit has $V_{ss}$ tied to the power ground, and appears to be different from the tested waveforms that show +/- gate voltages.

This same reviewer added that while the gate drive speed is fast, device overshoot voltage is nearly doubled, and he suggested that the team address whether there is any tradeoff.

The final reviewer described as one of the strengths of the project the team's pursuit of a spiral design/development approach involving the planned increase in capabilities with successive iterations. Not having clearly defined specifications for capacitive drive and dV/dt capability, however, is an oversight that needs to be corrected. This could/should have been defined early in the program based on the known goal for the inverter, which drives the sizing of the IPM. Without this definition, it is not clear (by design) that the technical approach can meet the final requirement with margin. It is not easy for a reviewer to know for sure that there is not an inherent limitation that causes the project to fall short or to produce an unfeasible (from a cost perspective) final design, even if it works. While this reviewer does not think that will be the case, he believes at this point it remains a risk.

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

One reviewer praised the coordination between ORNL and the University of Tennessee (UT) as outstanding, adding that the seamless integration of the direction, evaluation, and testing work at ORNL with the IC design at UT has yielded outstanding program progress and success. Another reviewer described the collaboration with Ben Blalock at UT, and through him a commercial foundry, as one of the top strengths of the project. However, this same reviewer pinpointed as a project weakness the lack of early collaboration with the suppliers of the wide bandgap power semiconductors to better define the real specifications and requirements of the gate driver, although the person did acknowledge that the program manager identified this issue in her presentation as a priority for correction going forward.

Another reviewer commented that one of the collaborators seems to be good at IC level circuit design, and urged the team to work coherently to ensure that all functionalities are included. One person noted that the work has been done at ORNL and UT, and they are working with a chip manufacturer for prototypes.

A reviewer stated that IC manufacturers probably are working on this, too, and expressed the view that collaboration with more suppliers is needed. Finally, another reviewer believes it could be useful to solicit the opinions of additional inverter design experts, and that there really are only a few doing leading-edge research into topologies that minimize turn-on/turn-off stresses on switches. This person recognizes that some experts may not want to participate for intellectual property security reasons, but he added that as an outside reviewer, it is not possible for him to know just how much external solicitation has been 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?**

The responses to this query were generally positive. According to one, the plans appear to address the issues involved, and there is not a better way to proceed. Another reviewer remarked that the recognition and honest report by the program manager of one or two current weaknesses, including a commitment to rectify them, coupled with the spiral design approach that allows for incremental improvements (as opposed to a high risk one- or two-fab-cycle program that often is the case with government-sponsored research of this type), suggests that the prospects for successful development of an attractive technology are outstanding. This individual's sole recommendation would be to consider reserving additional financial resources for more fab cycles, and in this regard he noted that the commercial industry recognizes that this kind of development usually requires room for more fab cycles. A third reviewer thinks the proposed future research is tailored nicely to address the critical limitations identified, including a concern about the ability of the gate driver to handle the necessary output current levels for large power modules. Integration of the gate drive into an intelligent module is a forward-looking approach that should make the technology even more valuable. There is, though, a need for some packaging efforts, especially vis-à-vis the integration into an intelligent module.

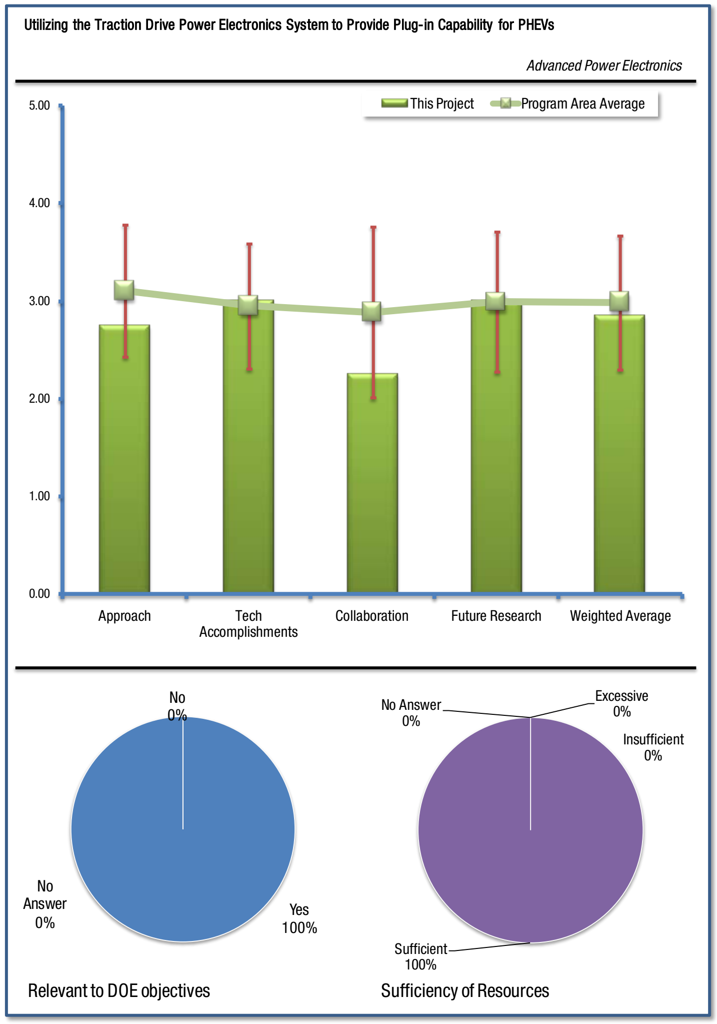
One reviewer identified fabrication of the actual gate drive IC for testing as a very important step to proving the concept, and looks forward to seeing the results in the next meeting. Another commented that the future work builds on improvements over Gen 2 and is very focused on overcoming the known barriers. This reviewer believes, though, that some effort should be made to address cost because this technology does not appear to be low cost.

One person stated simply that progress in optimizing the design for manufacturing is a bit slow.

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

Seven of the reviewers think the resources are sufficient; one thinks they are insufficient.

## Utilizing the Traction Drive Power Electronics System to Provide Plug-in Capability for PHEVs: Gui-Jia Su (Oak Ridge National Laboratory (ORNL))




**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?**

All of the reviewers were positive about the project. One reviewer said the charger concept is very interesting, and that it can reduce the cost of the charger drastically. One said it is a clever idea to cut cost, another described low-cost fast charge implementations as very relevant, and a third indicated that reduced cost and size (volume) are important factors in realizing the long-term success of HEVs/PHEVs, adding that work in the area of high temperature compact inverters is important. According to the last reviewer, PE system optimization and the pursuit of enhanced traction drive performance characteristics increase the efficiency and performance of the hybrid electric drive system. Efficiency improvements of these subsystems enable a reduction in fuel used by the ICE electric generation system, and if projected charger efficiency performance of the proposed inverter modifications are realized, DOE objectives can be achieved.

**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 pros and cons of the idea are not listed and tackled fully. Another felt that the fundamental limits of the technical approach should have been stated up front and clearly. First, it is not clear that a battery which operates above and below the peak voltage of the ac line can be charged using this technology. To avoid unregulated forward bias of the inverter diodes, the battery voltage must be greater than the ac line peak voltage (what is the minimum delta voltage that this topology will work to?). Second, bus capacitance must be large to suppress the 60 Hz fundamental; if low ripple dc battery charging currents are preferred, the traction battery impedance apparently needs to be much higher than the capacitor impedance. Third, what is the range of measured motor leakage inductances and are there issues with the technology working with them? Fourth, what is the required switching frequency (it ties back to the leakage inductance question) and at what switching frequency was the test conducted? Fifth, this method does not isolate the battery from the chassis of the vehicle. NEC code requires that the vehicle be grounded during an ac line charge. Does the work examine the consequence of tying the high voltage battery to ground and does it examine the impact on the filtering (Y-caps) that are implemented throughout the vehicle electrical system? Sixth, this approach must not lose sight of the need to supply auxiliary load power (12V dc) for the purpose of operating the vehicle electronics. The reviewer went on to state that this appears to be a current sourced inverter topology, and that it would be useful to understand the operation in the “portable generator mode” where a low impedance voltage source is desired. He wondered whether the investigator is planning on using the vehicle for the ground in this mode.

The last reviewer commented that the modified traction drive inverter systems being investigated do not have major technology hurdles to overcome, but require validation of the novel topology and battery charging concept. If successful, this topology will evolve directly to support future PHEVs as well as initial HEVs and directly addresses system level obstacles of cost and PHEV suitability. He would like to have seen some of the control design aspects of the conceptual modified inverter circuit and a discussion of the possible effects of regenerative energy and peak power demand periods (primarily with regard to battery protection), as well as explicit consideration of thermal aspects of high rate charging on motor reliability and projected lifetimes.

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

Of the three reviewers who commented, one stated that the key concerns of ground fault current flow, real world motor zero sequence inductances (leakage inductance), and allowable THD and THD at specific frequencies need to be understood. This individual noted that he specified 3% THD for the DC to AC converter on his PHEV vehicle, not the investigator's specified goal of 10%. He added that the technology needs to address the range of voltages at which a battery operates, including the absolute worst case minimum voltage and maximum voltage.

The second reviewer believes progress is being made towards the project goal, although he stated that the authors need to demonstrate that the proposed topology is superior to another topology, otherwise it may not make sense to continue. They also need to look into the broader system approach for the temperature and high efficiency operations.

The third commenter indicated that prototype fabrication and characterization at both 120 and 240V charging sources provides good substantiation of the project performance of the modified traction drive inverter topology. Measured efficiency, PF, and distortion values were impressive, but this person would like to see a comparison with respect to the competing motor/generator technologies being considered (PM IM's SR, etc.).

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

One reviewer stated merely that inverter suppliers shall be collaborated. Another said that many of his already-stated concerns may have been addressed; otherwise, he suggests that separate efforts be kicked off to try to understand their impact. A third reviewer indicated that OEM collaboration on safety issues is a necessary but not sufficient condition for this criterion. This reviewer feels that closer collaboration with energy storage and PE partners could add significant value.

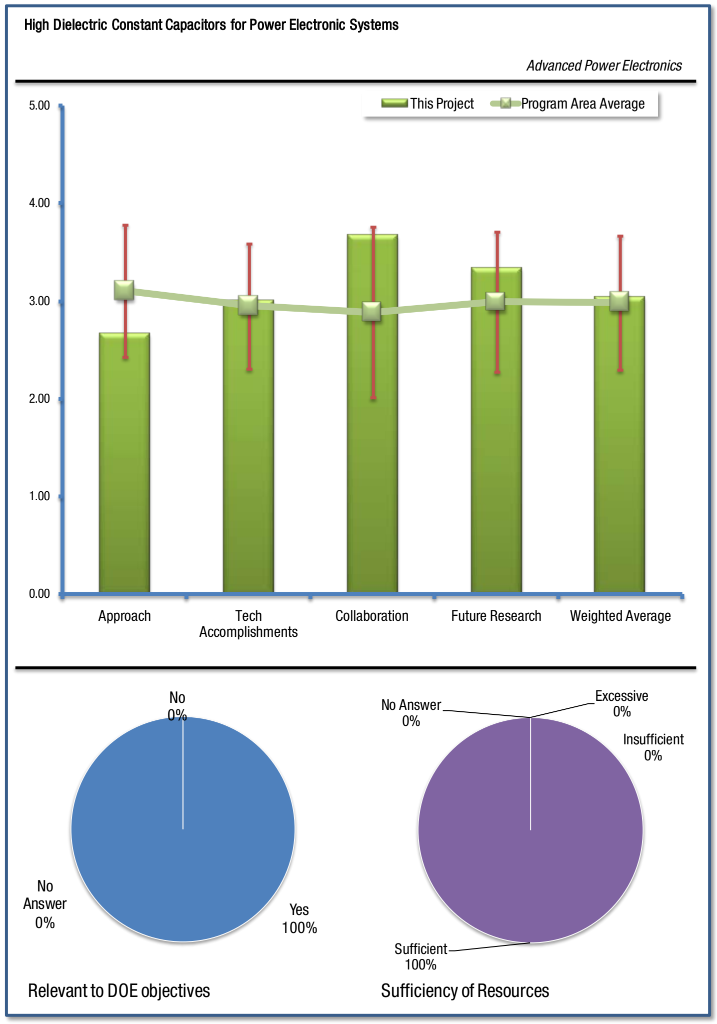
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

One reviewer reiterated his response to the prior question, i.e., many of his already-stated concerns may have been addressed; otherwise, he suggests that separate efforts be kicked off to try to understand their impact. A second reviewer remarked that FY 2010 plans appear to address the reviewers' risk concerns regarding cooling and control implementation, but explicit consideration of machine type and energy storage considerations should be included to project possible failure mode activation of these components for high charging rates, regenerative/peak power conditions, and thermal conditions.

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

All of the reviewers believe the resources are sufficient.

## High Dielectric Constant Capacitors for Power Electronic Systems: U. Balachandran (Argonne National Laboratory (ANL))




**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?**
One reviewer commented that capacitor size and temperature limitations are major barriers to low cost power electronics. Another believes that improving capacitors is an important factor in the reduction in size, cost, and capability to withstand automotive temperatures, although this reviewer is concerned about the ability to scale the technology up for large capacitance values. Similarly, the third reviewer stated that capacitors have been identified as a limiting component in a variety of power electronic applications, and that while the energy density appears to be state of the art, it remains to be demonstrated whether it can be scaled up beyond a stamp capacitor.

**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?**
Only one reviewer responded to this prompt, remarking that the dielectric properties look to be promising, but it is unclear whether the project has been tailored to the requirements for power electronics. What is the voltage for the application and will this dielectric material suffice? It is unclear whether the nonlinear capacitance (drop from k=1000 to k=65) will affect the capability to reduce the ripple voltage at the targeted voltage levels. Due to the high breakdown strength, it may not. It would be beneficial to obtain feedback from a power systems engineer to identify whether this is a limitation. If so, there may be a need to focus on reducing the drop in capacitance as a function of voltage.

Furthermore, it may help to obtain breakdown data as a function of electrode area and film thickness so as to identify degree of limitation for scale up, which was identified for future work. Would it be beneficial to evaluate the voltage breakdown strength for the dielectric when deposited onto a flat surface such as a silicon wafer? That may reduce defects induced by the foil.

Finally, this person posed the following questions: have microscopy techniques been used to identify the source of defects? Are there pinholes present within the film? Have the grain size and boundaries been investigated, since it is suspected to have an influence on the voltage breakdown strength?

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
In one reviewer’s estimation, progress is slow but moving on. Another stated that the effort has completed a thorough evaluation of dielectric properties, but it is a major challenge to scale up a dielectric to manufacture a prototype

capacitor. It would help to obtain feedback from a capacitor manufacturer to identify those limitations at an early stage. Moreover, the demonstration of the graceful failure was stated for a single layer, but it would help to see the characterization of the clearing site. Was the electrode or dielectric vaporized? It also would help to see the I vs. V or Capacitance vs. applied voltage plots to demonstrate the capability. There are techniques available to monitor the capacitance during a voltage breakdown test. Lastly, this reviewer explained that the TCC data look to be promising, but some of the other talks with respect to the applications indicated ambient temperatures up to 200°C or possible self-heating of the device due to large ripple currents. Will the temperature limit of 175°C for this material be sufficient or will its high DF value (8%) cause notable heat dissipation?

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

One reviewer thinks that collaboration with capacitor suppliers is needed. Another thinks the collaboration with Penn State will help verify the reported dielectric properties and enable a comparison with other high energy density dielectrics, and that it would be useful to identify a capacitor manufacturer so that the project can learn from previous scale-up efforts.

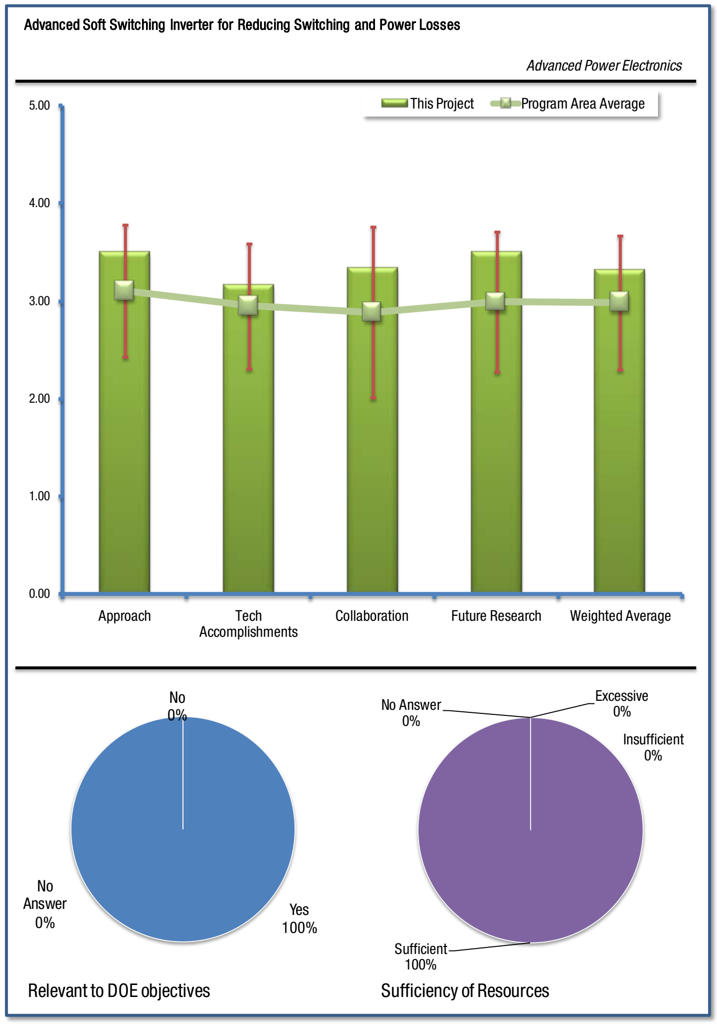
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

The lone respondent asked about the solvent's identity and whether it is an issue for scale-up efforts. Referencing the stated goal of increasing the area and thickness of the active dielectric in the capacitor, he remarked that it was not clear how this will be pursued or investigated, and with respect to the graceful failure, he stated that a discussion of the current understanding of the mechanism and how it applies to these dielectric and electrode materials and their respective thickness would be helpful.

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

All of the reviewers believe the resources are sufficient.

## 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?**
According to one respondent, lower loss devices are a key to improved thermal design and smaller overall packaging that affects volume, mass, and cost. Another indicated that the project is directly relevant to the programmatic goals of reducing mass and volume while attaining compatibility with the 105°C coolant requirement. A third reviewer commented that it is a new approach to driving the output, helps EMC, and saves cost. A fourth reviewer observed that by using a power module with lower thermal resistance, silicon size can be reduced, and if the silicon is smaller, then the cost is lower.

**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 described the project as being sharply focused on demonstrating the lower losses and EMI improvements. Another said that the investigator is addressing both modeling and hardware development and has broken down the milestones to independently address prioritized technical barriers, and that the project team demonstrates a clear understanding of the relevant technical barriers and milestones. Furthermore, they clearly understand the state of the art equipment and potential/attainable improvements.

One person agreed that using an integrated AlSiC baseplate can reduce the total thermal resistance of the power module, but noted that it is very expensive. A fourth reviewer suggested verifying the temperature rise on the module using an IR camera, and pointed out that in one slide the investigator shows a Cu base plate pin fin for his low thermal resistance module, while in the next slide he shows an AlSiC pin fin base plate. Is there a preference? What is the projected thermal resistance at the end of life on the Cu vs. AlSiC base plate?

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
One reviewer feels there has been very good progress to date, while another indicated that the project appears to be on schedule and substantially meeting the presented technical milestones. This person commented that the work/results are very thorough and well presented, appear to be well researched and validated, and are directly related to the project goals. It is noteworthy, he added, that the results are not limited to simulation.

A different reviewer offered three specific comments. First, slide #9 only shows the temperature difference between the junction and the baseplate. The temperature difference between the baseplate and coolant was not covered. Since the coolant temperature is 105°C, the junction temperature will exceed 120°C. Second, the cold plate performance and temperature should be verified through actual measurement. Third, the soft-switching topology was not included in the slides. Based on the pictures on page 12, however, the power stage is bulky (with 6 inductors).

A fourth reviewer asked whether a relative cost comparison for the soft switching approach versus a hard switch approach can be provided. What is reduced or eliminated in one approach versus the other?

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

One reviewer liked the collaboration with industry (Azure Dynamics). Another remarked that the extent and close coordination of the technical partners is clear from the presentation materials, and said that the accomplishments and experimental results demonstrate a well-coordinated effort. A third noted that while there are a limited number of partners, all seems to be working together. Finally, one person thought that suppliers need to be engaged.

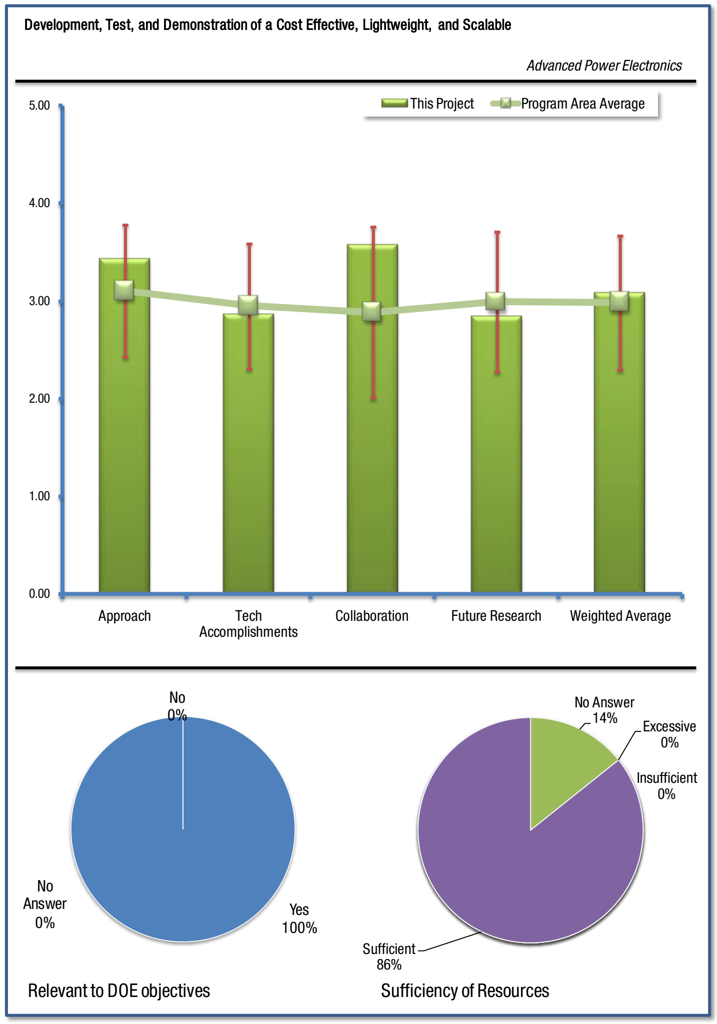
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

Three reviewers responded to this question, and all did so in a positive manner. One described the project as being well defined with a limited scope; seems very manageable. Another referred to it as a very focused project with an intent to verify on an EV to show lower losses and no EMI issues. This reviewer said he looks forward to understanding the integration of the additional gate circuitry and the manufacturability and cost analysis. The third respondent said the proposed future work is a logical extension of the previous efforts. The proposed tasks represent a full understanding of the existing results, and seem to offer a logical technical roadmap for realizing the greatest technical output from the program resources.

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

All of the reviewers believe the resources are sufficient.

## Development, Test, and Demonstration of a Cost Effective, Lightweight, and Scalable: Ralph Taylor (Delphi)




### Reviewer Sample Size

This project had a total of 7 reviewers.

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

Emphasizing that HEVs and PHEVs are important approaches to meeting DOE's petroleum reduction goals, one reviewer observed that the project consists of multiple coordinated technology development tasks of moderate to very high risk targeted at reducing the cost, volume, and mass of HEV and PHEV power converters. The individual tasks are integrated through modeling of the potential performance of each technology if they are successful. According to another reviewer, the project supports EV, HEV, and PHEV platforms with advances in inverter concepts using new capacitor materials, new semiconductors, new packaging concepts, and inverter topologies to improve weight, size, and cost of the vehicle power electronics. A third person commented that the work is aimed at more cost-effective hybrid propulsion systems. A fourth reviewer said this program is developing a comprehensive approach to high temperature inverters that, if successful, will enable greater market penetration of HEV and PHEV products. The greater fuel economies associated with these vehicles will enable petroleum displacement. Another reviewer similarly remarked that inverters represent the majority of the cost of current HEV powertrains, and therefore are one of the biggest determinants of widespread HEV market acceptance.

One person said this project is above just advanced development, and the outcome can go into production as soon as completed. The final reviewer stated that this work is aimed at reducing inverter cost thru advanced technology. Delphi is integrating several high-risk elements, including the advanced cap work with PLTZ and extruded film caps. The SiC work will be very challenging as well. The lowest risk will be the Viper package, which is still considered experimental by most OEMs.

### 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 referred to it as a well-designed project, with good use of alternative concept evaluation before deep-diving into detailed optimization, and also good use of dual-path contingency planning in such areas as film versus. film-on-foil capacitors and silicon versus SiC power semiconductors. Another reviewer said the team is well staffed with competent partners. A third thinks the multiple technology development tasks are well-coordinated through modeling, and the double-sided cooling, elimination of wire bonds, and integrated PCB approaches may result in power converters with a 10x reduction in mechanical part count and 2x size and 3x mass reductions. This same reviewer added that (1) the high heat transfer coefficient of the advanced heat sink task can reduce device temperature and help enable 105°C coolant, and (2) high temperature dielectric materials that can be made into films with good cost effectiveness provides the possibility of enabling an improved trade-off between cost and 105°C coolant operation. On the negative side, this person said the subtask of the Dow experimental investigation of SiC on Silicon claims to someday provide the same enhanced performance that recently has been demonstrated with other SiC materials but at a much lower cost; some in the SiC materials technical community think this subtask is ill-conceived and has no new innovation that would lead to success for this SiC on Silicon approach that has been unsuccessful in the past.

A reviewer thinks Delphi is really pushing the envelope of technology advancement. Integrating all these high-risk technologies is a real challenge, and this project will demonstrate how these will or will not work together. Most of these technologies are still a long way from commercialization, but the reviewer is glad to see that funding is available to do this work and believes that if the project is successful, it may lead to some exciting new power components.

One reviewer remarked that bottlenecks of going to a higher temperature module are being investigated. Yet another reviewer explained that the capacitor technology development approach at GE appears solid and the thermal modeling and packaging efforts are strong and well thought out. However, work on capacitors at Argonne is very speculative and possibly difficult to scale up to large capacitances. The work being performed at Dow Corning is extremely speculative and no data on this materials development effort has been presented for the last one and half years. In this person's view, Dow should present the status of their development effort in order to assess progress under this program.

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
Responses to this query were fairly mixed. On the favorable side, one reviewer noted promising developments, while another said overall progress has been excellent. The investigators are being hampered by the work in the area of dielectric on foil capacitors, but they are taking steps to improve the process and remove defects. Delphi has taken a multi-path approach to mitigate risk, and this looks to be wise since each path has significant risk. A third person referenced good progress on packaging and thermal management and high temperature film capacitors, but believes it is unclear how this approach to SiC semiconductors is different, i.e., what makes this project likely to succeed where others did not.

Another reviewer said good progress has been made in gaining an understanding of the process for capacitor materials, in developing large area capacitors, and in identifying materials for package and producing double-sided cooling packaging, etc. This same reviewer, however, thinks some tasks were not supported in the presentation material with sufficient metrics and evaluation data to monitor progress and determine the potential future impact of the developments. Additionally, 10 µm SiC on Silicon layers have been produced by CVD, but it appears that the SiC on Silicon material has not yet reached the quality necessary to demonstrate semiconductor electronic material properties. Future efforts, this person maintains, should have clear metrics assessing the progress of the material quality, and the team should be prepared to answer questions regarding the status of the material quality.

To another reviewer, actual accomplishments have been difficult to quantify due to vague milestones and metrics in this program, although there appears to be significant progress in identifying inverter topologies, packaging technologies, integration methods, and advanced cooling techniques.

On the decidedly negative side, one reviewer believes there is little evidence of the claimed progress.

**Question 4: What is your assessment of the level of collaboration and coordination with other institutions?**
With one exception, all of the reviewers who responded spoke positively of the level of collaboration and coordination. According to one, the inverter is a complex, multi-disciplinary product, and Delphi has done a great job of breaking down the development task into manageable pieces and leveraging component suppliers and ORNL and

NREL resources. Another said the coordination with NREL in thermal modeling, Argonne NL in capacitor materials, and ORNL in system modeling makes excellent use of competence in these areas. A third reviewer stated that this is a very high-powered collaboration with top notch partners, all of whom appear to be well integrated and coordinated, while a fourth person said the advance development teams, component manufacturers, and module producer are working together. Still another reviewer observed that the research and development team is broad and includes NREL for thermal modeling and simulation. It appears the lead (Delphi) is coordinating with other efforts.

The lone non-positive commenter said the effort seems not to be as coordinated as promised.

**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 responses here were mixed. According to one reviewer, Delphi provided strategies for pushing past barriers and also contingency planning to mitigate risk. Another thinks the future work will build on the past success.

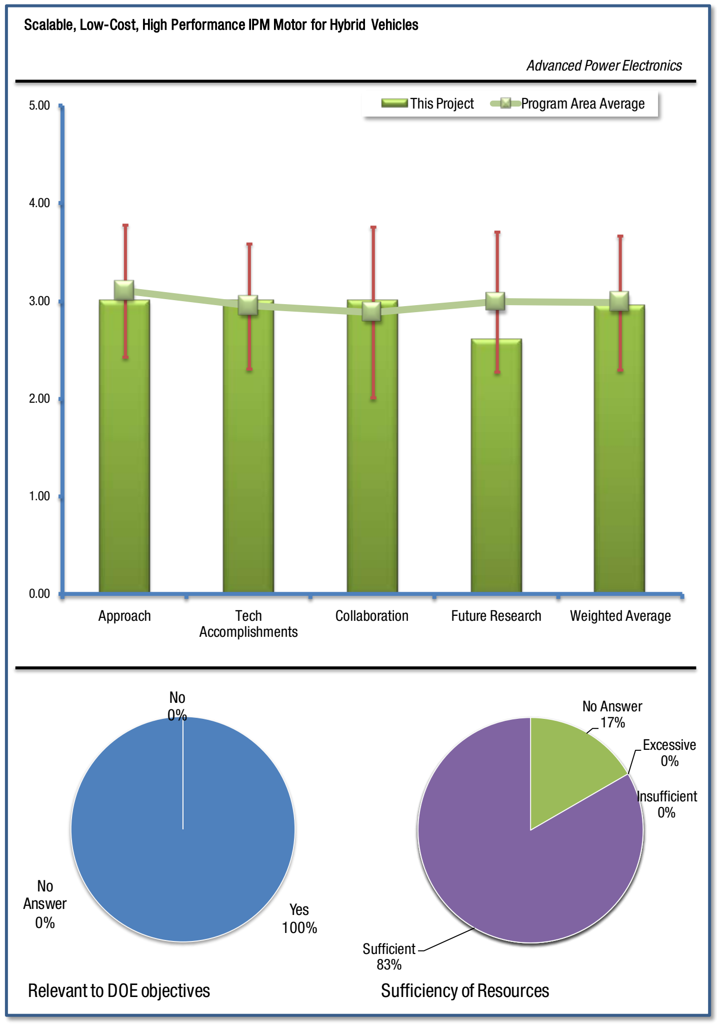
On the other hand, a reviewer commented that the description of future work provided in the presentation material was not detailed. This person expects to see a plan of how the project is being directed to address results of performance metric evaluations to meet program goals. Another characterized the proposed research as vague and not presented in detail. Future research should be broken down to include a timeline and milestones in detail.

Finally, a reviewer wondered how GM's purchase of the Delphi Kokomo plant is going to affect this work, and asked whether this project should continue under GM's overall system work.

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

Six of the seven reviewers responded; all believe the resources are sufficient.

## 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 6 reviewers.

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

According to one reviewer, motor efficiency and thermal capability are very important to the goals, while another said a low cost PM motor is a key to drive system cost reduction. A third said the project is targeted at low cost drives for HEVs, and a fourth reviewer remarked that this work is aimed at developing a very high efficiency electric motor, which may be key to high efficiency EVs and hybrids. Still another reviewer indicated that high efficiency motors are needed to optimize the range of EVs for specific battery capacity. This also minimizes the thermal management requirements. Finally, one person said that an efficient, high-power density BLDC motor is essential enabling technology for PHEVs/HEVs/EVs, and that this project hopes to double the current SOA in power density.

**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 assessed the approach as effective. Another assessed it as a realistic evaluation of a very aggressive DOE target efficiency goal and RPM range over which that efficiency goal must be met, and noted a willingness to take on new basic magnetic materials research to assist in meeting those goals.

A third reviewer noted that the team is investigating the use of a high resistivity microstructured magnetic material/alloy for efficiency improvement. Some other design considerations such as end-turn length reduction and new rotor design were mentioned, but no details were given. Design tradeoff on eddy current and hysteresis losses projected 95% efficiency at 325 V dc. The number is encouraging, but needs test verification.

To one reviewer, the approach seems valid, but there is not enough information on the results to evaluate the progress. The authors should provide test results to the EETT for evaluation. In the view of another, the technical approach appears to boil down to a careful engineering effort to optimize the normal design trades to emphasize rotor speed while keeping losses under control to maintain or improve efficiency. A key aspect appears to be the high-resistivity soft magnetic material. Beyond that, the reviewer could not respond inasmuch as nearly all details were withheld from the presentation. For this reason, this reviewer rates the approach as good, and he agrees that a careful engineering effort, rather than a science experiment, is what you would expect from GE, where a commercializable outcome is expected and desired.

To yet another reviewer, the DOE requirements are very challenging to meet. The investigators have focused on meeting efficiency by reducing the bulk resistivity of the soft magnetic composite material and magnets. While this approach will yield low losses, it also yields lower magnetic saturation flux properties, which in turn lowers torque density and increases motor volume. This person has reservations about the initial approach meeting all of the requirements.

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

One reviewer thinks there has been a great effort in materials research and motor topologies, and that thus far the accomplishments are very good. The real measure, he added, will be when the actual motor is tested and reported upon. Another reviewer said that with the assets of GE and its partners, hardware has been built and results obtained such that it is likely that the goals will be met, or at least closely approached. This research, he continued, is an example of how well-orchestrated projects undertaken in well-run commercial operations can be. A third reviewer characterized the design tradeoff study and simulation as key achievements, noted that the team filed more than 12 invention disclosures, but added that the most important hardware prototype testing remains to be seen.

To one reviewer, the final phase one report is needed before a full thumbs-up on the project can be given. A different individual expressed a similar sentiment, stating that while the approach seems valid, there is not enough information on the results to evaluate the progress. Again, the authors should provide test results to the EETT for evaluation. Still another reviewer stressed that very few specific accomplishments were reported in the presentation due to proprietary considerations. The project's management therefore is asking for “trust.” Given that there are major technical risks associated with magnetic materials and other more mundane issues like copper losses at the high rotor speed that don't really get addressed until Phase II, this reviewer found himself unable to get excited beyond a score of “fair” at this juncture. He felt this was reinforced in the Q&A period, when the speaker acknowledged that “re-scoping” will be required to deal with deficiencies in the soft magnetic materials.

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

Responses were mixed. One reviewer rated it as a very accomplished technical team, another remarked that close ties appear to be in place between materials vendors and motor assemblers, and a third reviewer indicated that a fair collaboration between universities and industry is in place, adding as well that the next phase should include a motor manufacturer.

The remaining two respondents referenced GE’s heavy role. According to one, it appears that the major effort and achievement are done by the prime contractor. The first prototype due in March seems to be delayed, and the presentation did not indicate contributions from other team members. According to the other respondent, the project has three qualified collaborators, but during Q&A the speaker said that 80% of the project is being kept within GE.

**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?**

Three reviewers provided responses. One responded that future research makes sense, adding that verification that the performance obtained is scalable will be important. Some barriers foreseen by this reviewer include process uniformity for magnetic materials to maintain magnetic characteristics and the high resistivity intended to reduce eddy current losses.

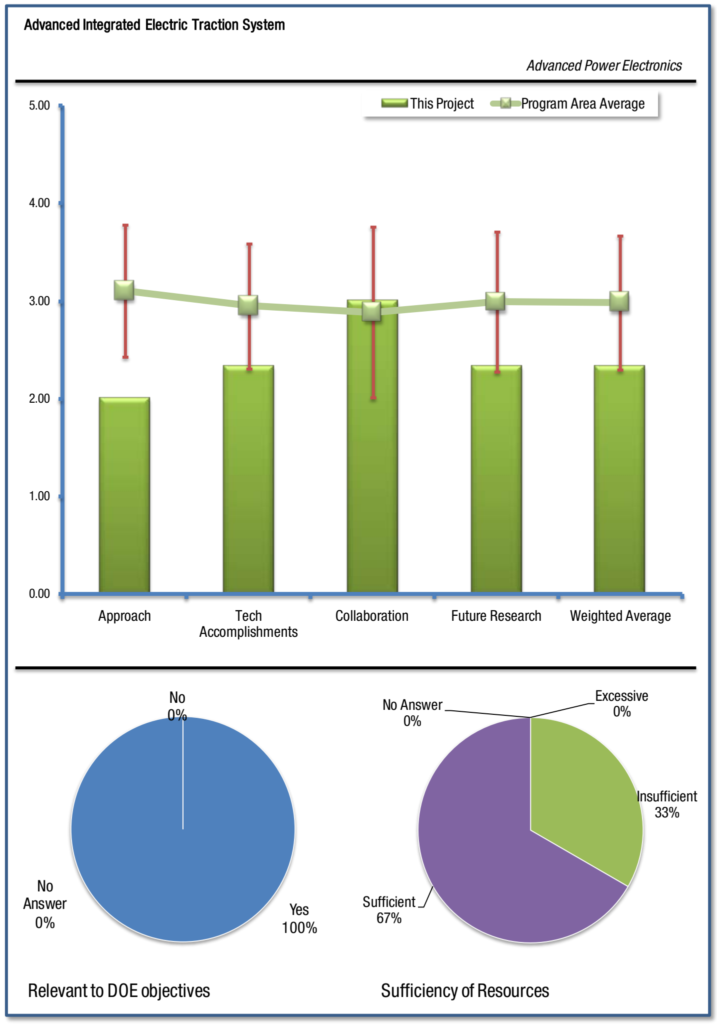
Another reviewer believes most of the real effort still lies ahead. Combined with the acknowledged need to re-scope even before Phase I is over, it looks like project management is getting its arms around what it will have to do to be successful, beginning with redefining success. The investigator emphasized that the original project goals were extremely aggressive, so some allowance for this risk should be given.

The third reviewer believes the current approach may not yield an optimal machine, and some redirection may be needed. There are still significant issues with the application of soft magnetic materials.

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

Five of the six reviewers provided responses; all believe the resources are sufficient.

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




**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?**
According to one reviewer, the project supports the overall objective of petroleum displacement by contributing to the development of electric vehicles (HEVs, PHEVs, EVs, and FCVs) that meet the DOE 2015 targets. It does this by providing 65 kW of continuous power and 120 kW of peak power for 18 seconds at a reasonable cost, low weight, and small volume, and with the use of engine coolant at a nominal temperature of 105°C. Another responded that the project is within the scope of the Vehicle Technologies Program, while the remaining reviewer believes research can find better ways to design TS for HEVs.

**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 questioned how details of the study will be shared with other OEMs or their suppliers. The second reviewer noted that the scheduling has sufficient program reviews and verification steps to ensure a good chance of first-time success. This reviewer described as good the design and testing process, and opined that the project depends quite a bit on suppliers for the solution of technical issues. For this reason, suppliers need to be chosen carefully for their specific technical expertise.

One reviewer explained that multiphase winding can deliver more torque than three-phase machines - this is common knowledge, so there is no need to understand it through extensive simulations. The cost and complexity of power electronics increases as the number of phases increases, and this reviewer does not see a feasible solution to that issue.

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
One reviewer said that considering the amount of funding, more should be accomplished, while another person said there has been little prototyping and experimental work.

In the view of another, significant information has been acquired on customer requirements needed for program success, and good substantiation was provided for moving in the direction of a 5-phase instead of a 3-phase system. In addition, the reviewer mentioned excellent consideration of new technology to address high temperature packaging issues, including double-side soldered chips, new interconnection technology, use of high temperature PP capacitor, and improved board technology. More technical details on the packaging approaches suggested could be provided. Overall, this reviewer believes there is not enough information to assess the chance of success.

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

Two responses were provided. One complained that the detailed effort at collaboration was not spelled out clearly, while the other reviewer found very strong dependence on the supplier network, which seems well integrated with the program.

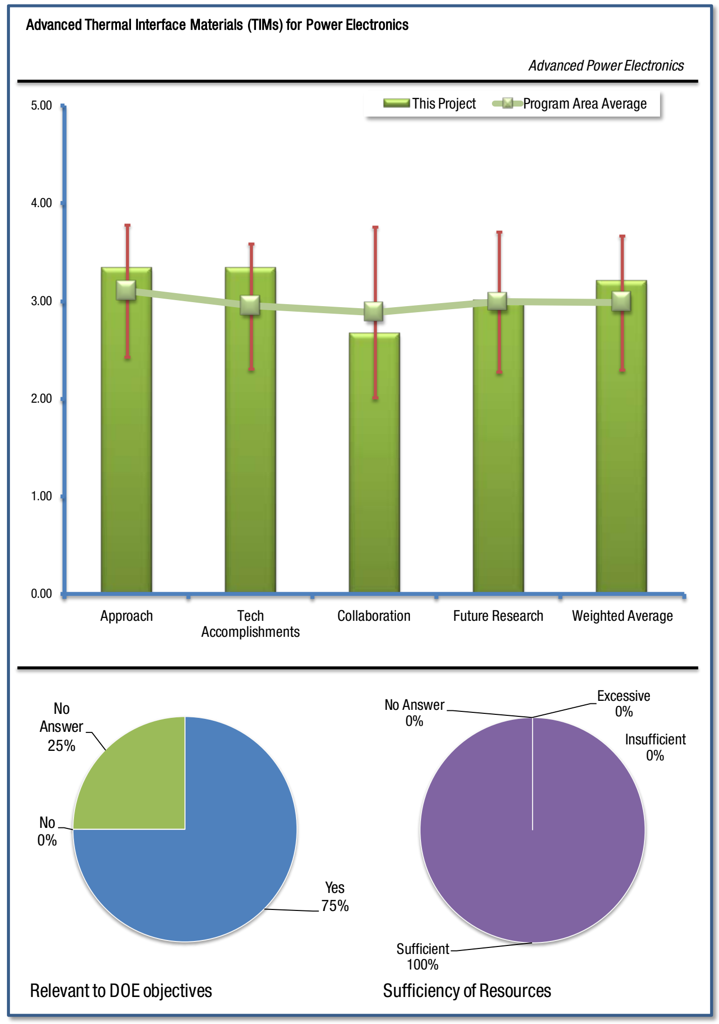
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

To one reviewer, the plan focuses on past progress, and future research is focused on integration and demonstration of the technology in the prototype form. With the funding that has been spent, much more could have been accomplished; for example, this reviewer would have expected a motor system that has been tested and integrated in a GM HEV/PHEV.

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

Two of the reviewers think the resources are sufficient; one finds them insufficient.

## Advanced Thermal Interface Materials (TIMs) for Power Electronics: Sreekant Narumanchi (National Renewable Energy Laboratory (NREL))




**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?**

One person remarked that thermal interface materials can increase the performance and life of power electronic components, while another indicated that because TIM packaging materials represent the largest single component to the thermal impedance of a packaged electronic device, the junction temperature and therefore forward conduction losses can be reduced measurably by eliminating or reducing this significant contribution. Reduced junction temperatures mean reduced losses, higher efficiency, improved reliability, and reduced fuel consumption.

**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 one reviewer who responded stated that survey and analysis of available commercial and R&D TIM choices is a good benchmark or baseline metric. The modeling approach toward characterizing the physics of thermal transport at interfaces or on small dimensional scales should have been presented in terms of models or approaches being pursued. In addition, the data relating to CNT $R_{th}$ overestimates the values actually achieved in laboratory experiments. Alternative approaches to bonded approaches are extensive and should be investigated beyond Ag nanopastes. Hopefully, the research is adequately focused on the reliability aspects of TIM material performance with respect to thermal cycling over the entire operational range of temperatures expected in platform. Static performance is not necessarily the primary consideration if $R_{th}$ increases with cycle life, i.e., CTE matching or grading of bonded approaches.

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

The one respondent found that there has been good progress on the evaluation of existing TIM material options, and sees no reason why the modeling activity should not have proceeded in parallel. A true lack of physical understanding of interfacial heat transport exists and progress in addressing this issue could be significantly beneficial. The investigator should have conducted a more thorough analysis of bonded approach options and materials; the potential list is extensive and opportunities for innovation exist.

This reviewer also believes that the significant effort that has been expended on developing characterization capability, while to an extent necessary, may have been too extensive. Collaboration with numerous academic groups with existing characterization capability would have been a more effective use of resources.

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

According to the lone commenter, there appears to be good coordination with module manufacturers and system integrators concerning the technology being developed and evaluated.

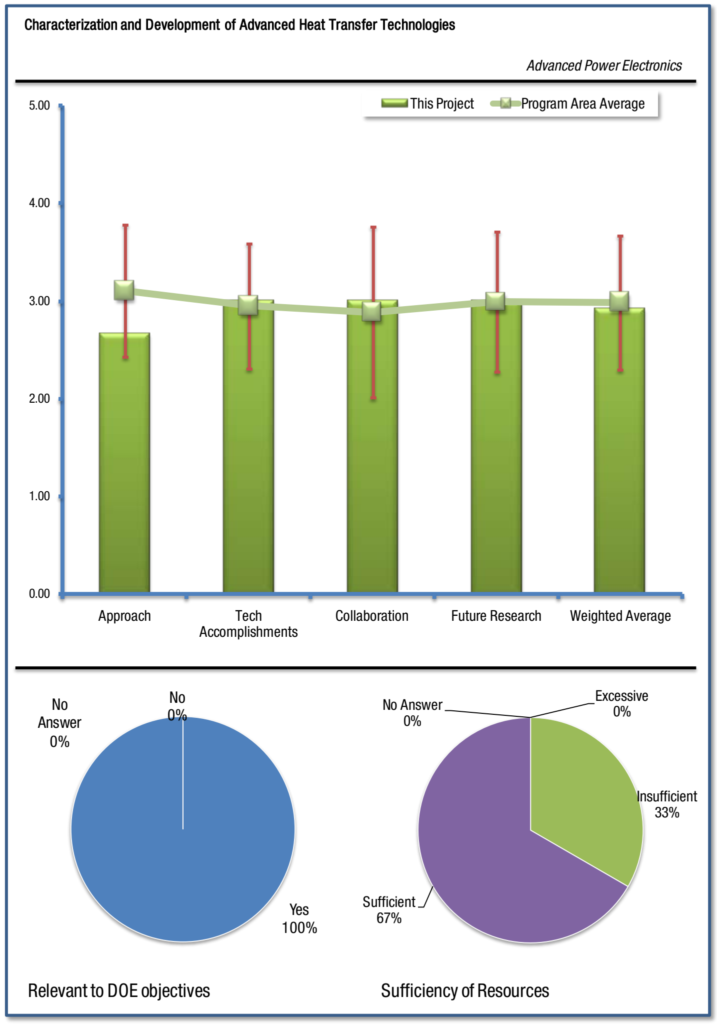
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

In the view of one reviewer, a new material or bonding process should be explored, while a second reviewer believes the future plan is consistent with the project goals.

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

All of the reviewers rate the resources as sufficient.

## Characterization and Development of Advanced Heat Transfer Technologies: Kenneth Kelly (National Renewable Energy Laboratory (NREL))




**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?**
One reviewer replied that improved heat transfer is critical to reducing volume, another stated that the project will enable high power modules to operate at a higher coolant temperature, and the third indicated that the thermal system limits utilization of power devices, and this low utilization adds 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?**
According to one reviewer, questions of cost and reliability need to be addressed further as part of the approach. According to another, while the investigator addressed the need for automotive thermal solutions, the data supplied was at time 0. Can data be supplied that shows performance over the product's lifetime, and how can you show that erosion or contaminants do not degrade the system over time?

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
One reviewer referred to good technical work but sees the need for a greater focus on how the project will overcome key barriers like cost and reliability. Another believes the degrading or failure modes of impingement systems need to be addressed. How is low cost defined for the applications? Is that a piece cost analysis or a system analysis, and if the latter, what assumptions are made? What are adders and subtractors (especially for impingement, may need a pump, filter, material coatings, closed system; while the gain possibly may be less silicon area).

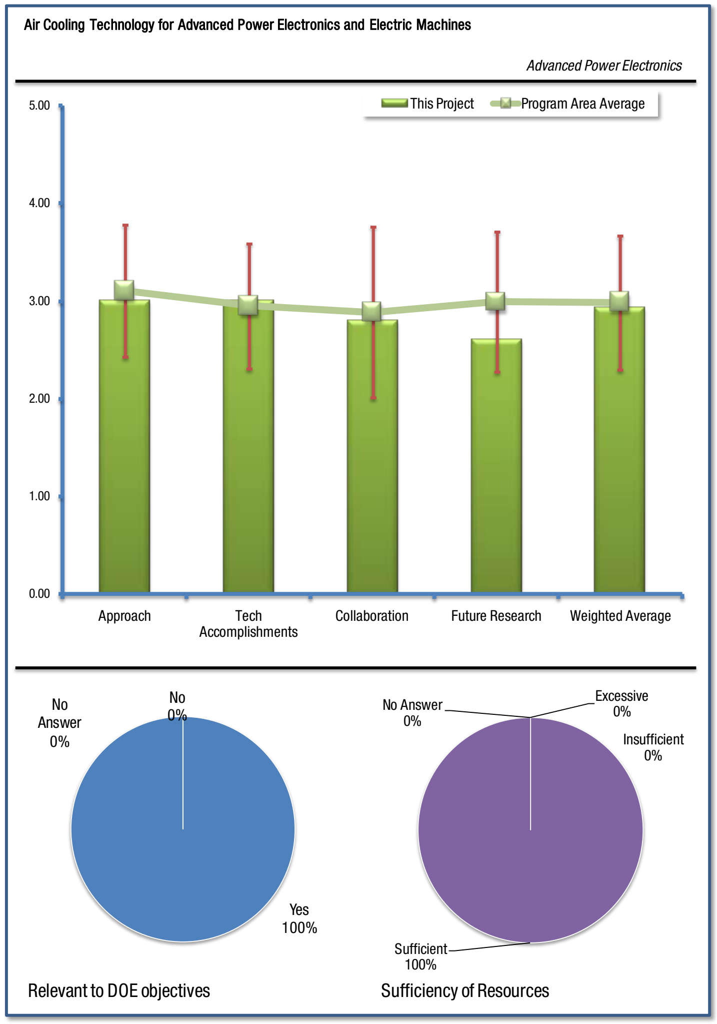
**Question 4: What is your assessment of the level of collaboration and coordination with other institutions?**
One reviewer found good cooperation with industry and open sharing of information, while another feels that collaboration with tier 1 suppliers would help greatly in addressing the cost and reliability issues. This reviewer also points out that work was done on the Semikron inverter, but no relative cost assessment has yet been performed.

**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 thinks the investigator needs to address the cost and reliability issues. Another thinks the future work on surface enhancements will be of interest, and wonders whether the investigator will look at the products from Wolverine Tube that are doing these surface enhancements commercially.

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

Two of the reviewers rate the resources as sufficient; one finds them insufficient.

## Air Cooling Technology for Advanced Power Electronics and Electric Machines: Desikan Bharathan (National Renewable Energy Laboratory (NREL))




**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?**
According to one reviewer, if air cooling could be used instead of liquid cooling in HEV and PHEV applications, the cost savings could be significant and would lead to greater market penetration and associated petroleum displacement. Another observed that such cooling can eliminate the need for a second cooling system, while a third reviewer stated that if successful, air cooling can enable higher power density and lower cost. Still another reviewer noted that air cooling is desirable in many power electronics cooling applications, and generally leads to simpler designs and low mass and power consumption. Describing HEVs and PHEVs as important approaches to meeting the petroleum reduction goals, the last reviewer noted that air is an important alternative to liquid cooling, providing lower weight and cost with a trade-off in higher volume and additional fan power requirement. Simplicity also is an advantage of this approach.

**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?**
Among positive reviews, one person found the technical approach to be well conceived and executed. The technical barriers are clearly defined and understood by the investigators, and addressing them appears to be guiding the progress of the project. Another believes the project is dealing with the higher volume and parasitic power barriers that need to be addressed with air cooling of propulsion inverters. In this commenter's view, the use of CFD simulation to design air cooling alternative high performance air cooled heat exchangers is important and NREL has good capability. However, the project should include more close collaboration with inverter programs and should include a detailed plan of how the cooling system will be integrated with the inverter.

To a third reviewer, the approach is logical and systematic, and moving to experimental validation as quickly as possible is preferred. This reviewer recommends providing a clear comparison with liquid cooling so that one can better understand how the current project effort compares to the state-of-the-art, and specifically questions whether 30°C ambient air temperature is a realistic assumption. Ambient temperatures can go to much higher levels under the hood. This adds a lot of tubing and pipes in the system and will significantly increase the overall system weight compared to liquid cooling. This issue needs to be carefully examined.

One reviewer expressed a desire for a more detailed project plan so that one can know what the next tasks are and how resources are to be utilized. In the opinion of another, a stronger case needs to be made that the air cooling will be adequate for high power HEV and PHEV power electronic systems. The issues of parasitic power, air filtration, and noise suppression (if required) also need to be addressed aggressively. It is not obvious from the presentation and the results to date whether a solution that overcomes these challenges in a manner that could lead to a real world product can be identified.

**Question 3: Characterize your understanding of the technical accomplishments and progress toward overall project and DOE goals.**
According to one reviewer, the project has developed an improved air flow heat removal approach, has validated the approach and design with hardware measurements, and has demonstrated good performance. Another thinks the investigator has made significant progress; the results attained suggest that programmatic goals may be met, and the innovative heat transfer surfaces designed by the project team suggest that significant performance improvements may be obtained with attendant reduced costs and system mass.

One reviewer found good progress, but believes a clear system comparison of air versus liquid cooling needs to be carefully performed. Another asked for an identification of the major breakthroughs and the next step.

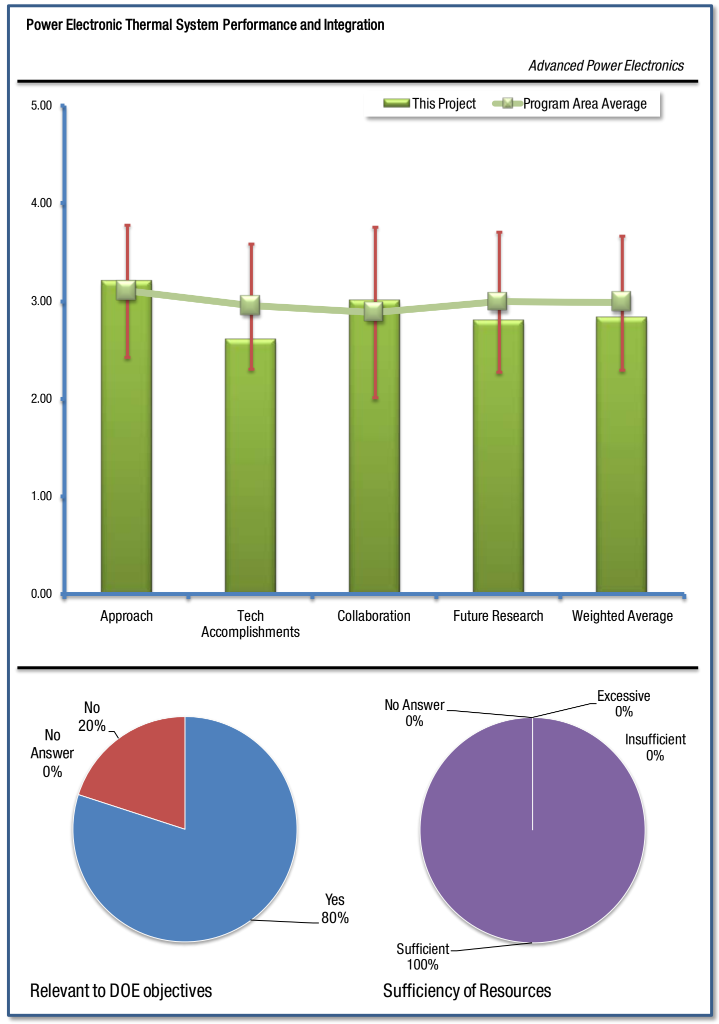
**Question 4: What is your assessment of the level of collaboration and coordination with other institutions?**
One reviewer thinks there is good collaboration with external partners (DOE is providing funding solely), and another found that the investigator demonstrated collaboration with technical partners, and that the NREL project lead is coordinating interactions with the needs/requirements of industrial and government partners.

A reviewer believes the project should consider collaboration with one of the inverter teams to integrate cooling hardware with inverter hardware because issues related to vehicle integration, inverter integration, and integration with power electronic component packaging have not been addressed. One person observed that most DC/DC power converters use air cooling, and asked whether there is any collaboration 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?**
To one reviewer, the proposed future work will address the most pressing technical needs. These efforts are anticipated to yield the greatest technical and programmatic impact, i.e., DOE should realize the biggest bang for its buck. To another, the proposed future work spells out the key challenges without a specific proposal of how to address them. Finally, one reviewer thinks that the plan to “develop guidelines for performance estimation, cost, volume, weight, and other measures for industry” does not seem reasonable without having fully considered the integration with the inverter; similarly, the plan to “develop second iteration design and demonstrate air-cooling” does not define the reasons and goals for a second iteration.

**Question 6: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?**
All of the reviewers believe the resources are sufficient.

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




**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?**

To one reviewer, finding the optimal package to dissipate heat in the most efficient way is critical. To another, the computational framework allows a comparison of various thermal management techniques at a system level for optimization/investigation of integration scenarios. A third reviewer maintains that thermal management strategies will have a significant impact on the size, cost, available power, and weight of EV power conversion and electric machines, and that a reduction of any of these factors will make practical EVs more palatable to the general public. One reviewer believes the work should be a subset of power electronics system development, not a standalone project that has very little linkage to a real system. It can be considered as analysis tool development, but it is too general to be a key DOE project under the advanced power electronics program.

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

A reviewer found that a comprehensive approach was presented for computational assessment of thermal management techniques that includes FEA 3D heat flow analysis coupled with fluid dynamics to realize realistic thermal models for comparison of proposed cooling designs. This reviewer observed that the main approach appears to be coupling of CAD and FEA packages along with code to perform parametric analysis for possible optimization of thermal management approaches. It is unclear, however, how this work is actually made useful to the vehicle industry where it is needed most. It also is unclear what level of throughput is possible to make this approach useful in an engineering scenario.

Another reviewer considered the characterization of temperature response to transient loading in the frequency domain to be an interesting idea, albeit one that takes a bit of work to grasp. As in, what is the temperature response to power input fluctuations converted to a spectrum; different heat removal techniques have a thermal transfer function that defines differences between strategies.

One reviewer noted that there are companies working on packaging thermal simulations and design enhancements, such as Mineware in Novi, Michigan. More collaboration with these companies is recommended to speed up the progress. A person pointed out that the thermal impedance was evaluated with different thermal management techniques and frequencies. It is unclear in terms of the impact to the actual system. Some real system examples need to be examined with real numbers, instead of the general curves shown in the presentation. The plan on analyzing the system level thermal performance covering the chassis, power devices, and capacitors is important, but again, some realistic numbers need to be included in the presentation.

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

In one reviewer's assessment, the technical accomplishments presented meet the program goals and also are progress toward the overall DOE goals. The key technical accomplishment of generating publicly available reports for engineers and vehicle makers to access appears to be extremely useful. Another reviewer specifically asked, what are the results of the analysis of Toyota dual surface cooling compared to Delphi's and current single side coolings? A reviewer observed that the accomplishment shown in the presentation did not address the specific system and is too general, while a different reviewer found that the detail presented is so granular, it is difficult to determine what is behind the presentation. The capacitor model would be interesting to compare to what others in the capacitor industry have come up with. Capacitor models are more complicated than one might initially think. Anisitropic thermal conductivity and dissipation as a function of axial location within the capacitor are just the tip of the iceberg if a simulation is to be representative of a real capacitor.

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

One reviewer found the cooperation with Delphi to be a plus, while another recommended more collaboration with companies working in this field. To a third reviewer, interaction with OEMs is the key area where this effort will have an impact, and it appears the performers are working with the vehicle makers to understand the design tradeoffs of the varying approaches to thermal management.

**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?**

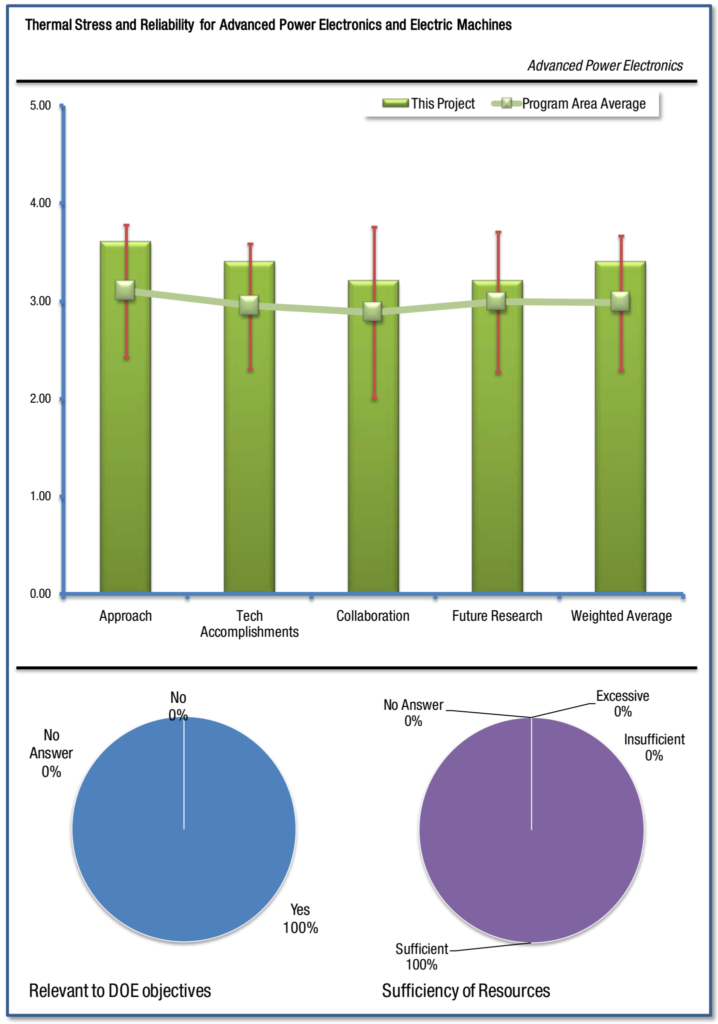
One reviewer sees the proposed future research as being consistent with the approach, primarily in the interaction with industry, to add relevance to the research program. Another key area is the investigation of uncertainty and variations that are difficult to analyze empirically. A reviewer believes the best future work would be to examine various thermal management strategies to determine an optimum "complete vehicle" solution direction that appears to best straddle the cost and performance goals. This reviewer adds that you cannot always get what you want when limited by wallet contents, but if you are careful you might get a good deal on something that is useful. In his estimation, this is what the US consumer is looking for in an EV.

Another reviewer wondered what the project deliverables are, what the thermal simulation tools are, and what the design guidelines are.

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

All of the reviewers rate the resources as sufficient.

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




**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?**
According to one reviewer, the reliability of power electronics components and life expectancy is important. The question is, how different is it from other power devices that have been out there for many years? For example, what tools were used by the industry to test for wire bond durability?

Another reviewer said this appears to be a solid system engineering study (with the “correct” answer not preselected), with adequate component detail for the conclusions not to be misleading or trivial.

A third reviewer stated that the project supports the overall DOE objective of petroleum displacement by overcoming the barriers to the adoption of low-cost, petroleum saving PEEM technology for a wide range of electric vehicles (PHEVs, HEVs, EVs, and FCVs). It does this through the enhancement and demonstration of the reliability of the PEEM technology via the development and use of CAE tools for design-for-reliability. These tools permit the cost-effective development of the technology by guiding R&D decisions, reducing deployment time, identifying barriers to meeting life/reliability goals, and increasing product robustness.

One reviewer said merely that the thermal issue is an essential part of the problem.

**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 a prototype validation would be necessary for the study.

According to a reviewer, the work appears to be technically commensurate with the objectives. The scientific/engineering know-how and tools appear to be at least the minimum level of complexity (two dimensional FEA). Are three dimensions (or perhaps 2.5 dimensions) necessary to make a claim about “reliability” that doesn't lead to unexpected and nasty surprises? This reviewer realizes that “validation” is supposed to be the answer, but would say that in the absence of a commercially qualified experience, both calculations and empirical data can be misleading. Looking ahead with the best physics-based understanding of the problem is the best defense (e.g., how do you characterize solder?).

According to a different reviewer, the program focuses on making the PEEM technology more reliable using the latest physics-of-failure approaches to robust design and validation. These approaches focus on the development and use of cost-effective modeling and simulation to build reliability into the product upfront in the design cycle and validating that reliability in the final product to minimize testing cost. The application of this approach to three specific APEEM packages for which there is validation data focuses the program to a strong degree. The three packages chosen cover a range of thermal management and packaging approaches that have widespread application. Furthermore, the emphasis on wirebonds, die attach, and DBC attach issues hits the dominant failure mechanisms for power electronic modules.

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

One reviewer maintains that, in the absence of immediately available and reliable experimental data, excellent use of the literature was substituted to give a measure of interim confidence. Another stated that the team has made progress in setting up the models and simulation, and has an understanding of the fundamental issues and different possible configurations. A third reviewer believes excellent progress is being made toward program goals, with all the supporting information for the simulations being gathered and characterized in this year's work, including the definition of thermal boundary conditions, material properties, and fatigue properties of soldered and sintered interface. In addition, thermal modeling has been conducted. This will lead to the process of validating models versus test data and comparing life implications in next year's work.

One reviewer found that data are as expected, with one exception - where topology 3 took 10,696 cycles to failure and topology 2 took 11,982 cycles. Why? Was the failure due to direct spray on DBC?

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

One reviewer found good informal interaction with other national laboratories (ORNL), other government institutions, and academic institutions to gather reliability, modeling, and technology inputs. This reviewer also found good tech transfer of the results to industry. Nevertheless, it was not clear to him whether there are any formal partnerships with any of these institutions.

Another reviewer saw some interaction with ORNL and academia, although more is desired with industry (supplier involved in thermal solutions) and academia in the electric engineering field.

One individual did not see any collaboration with industry experts and chip makers. They should have the real-life experience and expertise on the reliability of these power devices.

A reviewer felt that collaboration was described in general terms. It might have been useful to describe the validation plans in greater detail, which also would highlight the value of collaboration and coordination in this project.

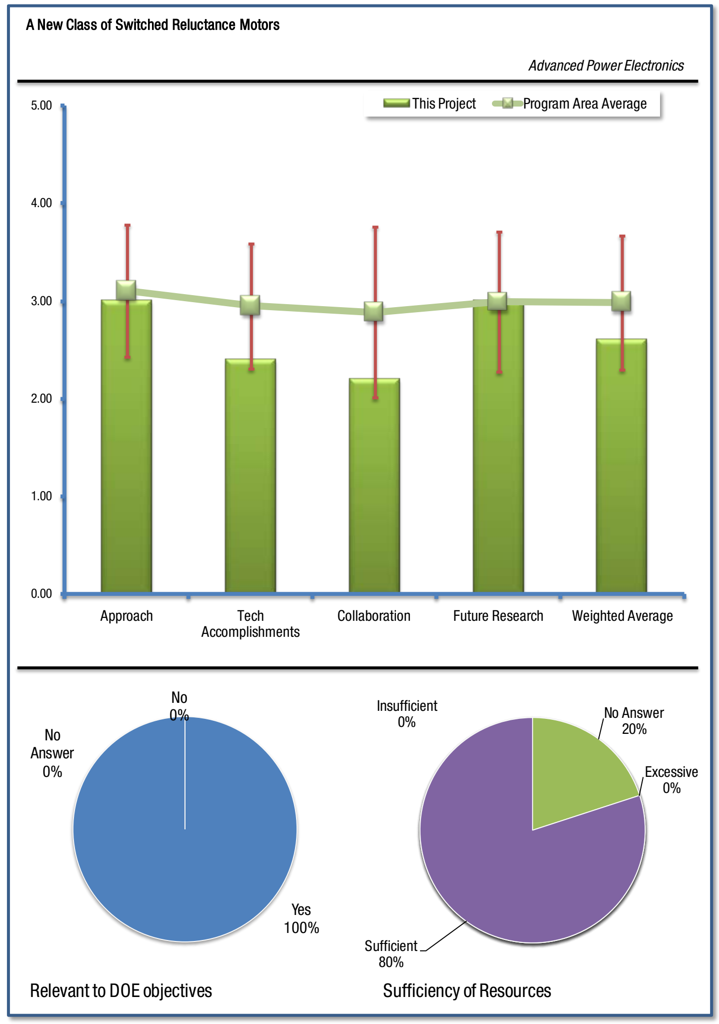
#### Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?

Of the three respondents, one stated that the project looks very promising, although he did not see enough information about the empirical validation plan to feel fully comfortable with the going-forward plan. Another remarked that the next steps of validation and calibration of the modeling using test results, completing the comparison of the reliability of the different technologies, and an analysis of variability are all important and necessary tasks to complete this effort. The third respondent suggested that the investigator consider validation through experimentation, and involving real world systems from EE side so that the failure mechanism can be truly understood.

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

All of the reviewers think the resources are sufficient.

# A New Class of Switched Reluctance Motors: Tim Burress (Oak Ridge National Laboratory (ORNL)) - POSTER




**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 a motor which does not use PM may be needed in the near future, and that cost is important, too. Another noted that the work may lead to a low cost motor by reducing the amount of permanent magnets. Still another said the project is targeted at developing affordable hybrid propulsion systems.

One person observed that this has the potential of being low cost, but that noise with SR motors must be addressed up front to determine viability. The final reviewer remarked that EM technology development and performance improvements focused on overall vehicle efficiency reduces fossil fuel requirements for fixed loads. The foci of this project on SRM flux leakage and torque ripple reductions both address efficiency improvements and thus classify this project as effecting petroleum displacement. The novel SRM being pursued has the potential to increase power density and thus weight, reducing fuel requirements.

**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 described the approach as well structured. Another said it is too early in the project for a real critical assessment, although he noted the approach looks good due to initial investigation and later downselect. A third reviewer believes the project addresses critical SRM issues dealing with complexity and cost (reducing # poles), flux leakage and mag material losses, and potentially cost. The program therefore is focused on the key SRM issues hindering pervasive adoption of this technology in a variety of platforms. It is a comprehensive and thorough investigation of novel SRM technologies that may yield significant benefits to motor size, weight, and cost.

Another reviewer wished he knew what the novelty of the design was so that he could make a better judgment. According to the remaining reviewer, the principal investigator claims to have solved many of the typical SRM issues. However, the little data presented from computer simulations shows an unacceptable torque ripple for vehicle applications. Although torque ripple is not included in the requirements, it is a significant concern because of its NVH implications. Unfortunately, SRM technology is notorious for its torque ripple, and this approach seems to emphasize that aspect even more.

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

According to one reviewer, the modeling milestones appear to have identified several promising approaches to both the motor design as well as the control algorithm. He rates the project as very nice work.

To a different reviewer, the early results look promising, while to another, we are still waiting to find out what the actual approach is. In a similar vein, a reviewer believes it is too early to really tell. Yet another person said that at this early stage, there are only modest analytical results that indicate an improvement over conventional SRM. The principal investigator did not disclose the motor topology.

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

Comments were varied. One reviewer saw no collaboration with any manufacturer of industry expertise, and another said there has been no information sharing with OEMs due to ongoing patent work. A third indicated that most of the work is being done at ORNL, while a fourth remarked that while the UT connection is good, the project likely would benefit from coordination with a historical SRM manufacturer.

The final reviewer believes that for such an early stage, the collaboration level is appropriate.

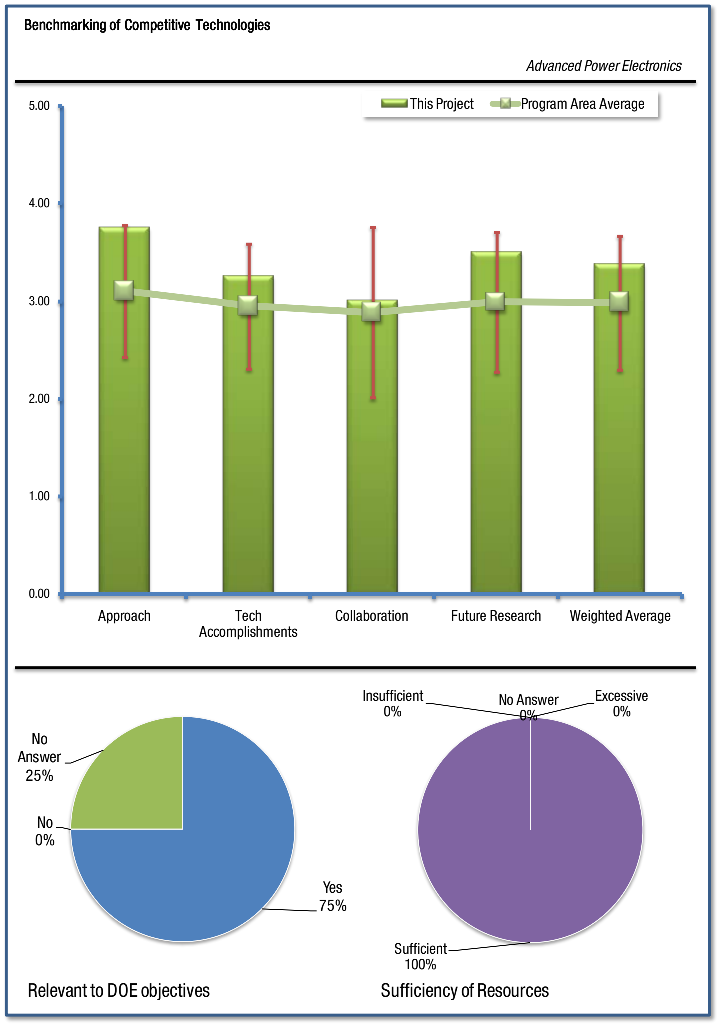
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

Once again, the responses were mixed. On the positive side, a reviewer rated the project as very well organized and focused on the key issues. Another said the principal investigator understands the barriers and limitations of past switched reluctance designs and is trying to overcome these obstacles. A third reviewer thinks the plan is extremely vague and generic.

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

All of the reviewers think the resources are sufficient.

## Benchmarking of Competitive Technologies: Tim Burress (Oak Ridge National Laboratory (ORNL)) - POSTER




**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?**

Two reviewers alluded to benchmarking's importance to understanding the state of the art, while another remarked that benchmarking would help us to understand where the competition is and learn their unique ways of design.

**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 explained that if there are technical barriers to the analysis, it is not clear what they are. He asked whether those test barriers can be presented. There may be some knowledge that has been gained that can be used by industry so it does not need to reinvent. This shared knowledge may help speed the time to market. Could this be a lessons learned database?

Another person said it is a clever method to run the competitive modules and gather functional data. High mile data is useful, too, for understanding life endurance.

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

One reviewer noted a good report on Toyota vehicles. To another, the analysis is well done, although several questions were raised, i.e., how can the work be more widely distributed, is any effort being made to understand and document the control algorithms used, and if Argonne is doing this work, can a link or contact be provided to get access to the information?

One reviewer said the results are not as fast as he would like, but considering the budget and resources, he is very satisfied. A different reviewer commented that a focus on quick turnaround will result in improved value.

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

Among the responses, one reviewer found a very good information exchange with OEMs with respect to EETT reviews. Another reviewer feels that increased collaboration with industry (USCAR) to identify critical data and procedures will bring more benefit.

A reviewer queried whether the results of others' benchmarking activities can be collected and attached as an appendix, and one reviewer asked why, if Argonne is doing the control strategy documentation, no reference is made in the presentation to their work?

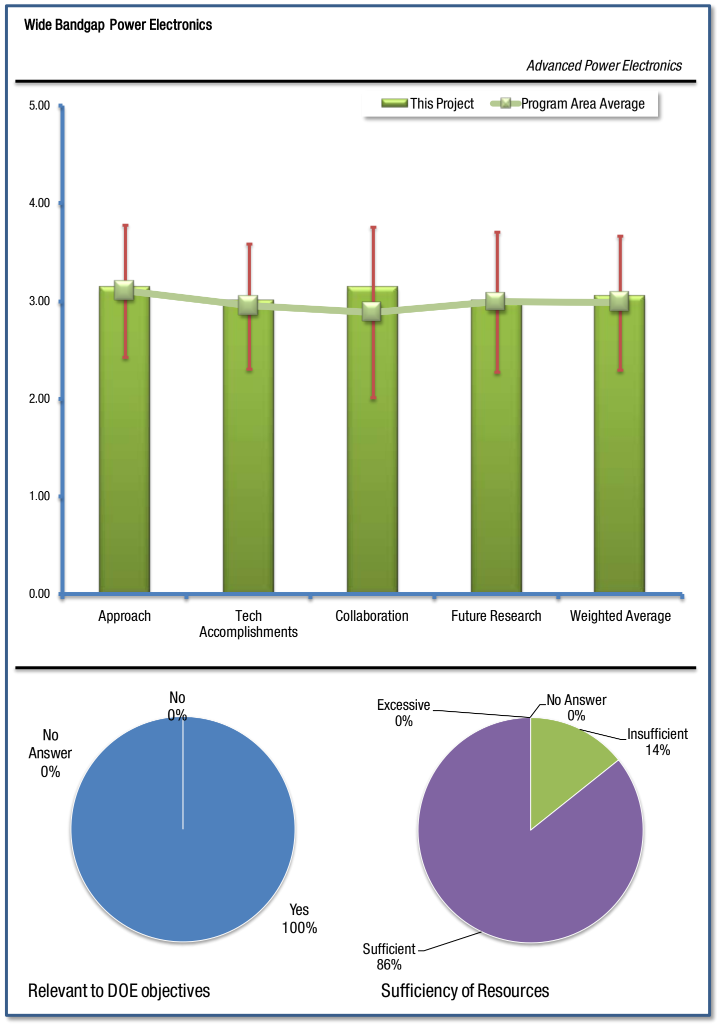
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

One reviewer remarked that the work on surface enhancements will be of interest, while the other respondent queried that if the focus of future research is shifting to PHEVs, whether the benchmark vehicle should focus towards a BYD F3DM PHEV.

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

All of the reviewers think the resources are sufficient.

## Wide Bandgap Power Electronics: Madhu Chinthavali (Oak Ridge National Laboratory (ORNL)) - POSTER




**Reviewer Sample Size**

This project had a total of 7 reviewers.

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

According to one reviewer, WBG devices are critical to lower loss, higher temperature operation that will enable smaller packaging, reduced mass, lower cost, and higher efficiency inverters. Another reviewer stated that such devices are a key promising technology for high efficiency power conversion technology.

A reviewer commented that an air cooled inverter is desired to eliminate the cooling loop, and if temperature operation is improved, then the inverter can be moved inside the transmission. Still another said that SiC devices have the potential of meeting the high power density and high coolant temperature targets, assuming the cost is going to go down in the future. Finally, a reviewer stated that wide bandgap power electronics are one avenue for reducing HEV system cost. This can be accomplished by eliminating liquid cooling and decreasing the overall size of the inverter.

**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?**

To one reviewer, the WBG device level testing is key and fully supported. However, it appears an “air-cooled inverter design” project has developed within this project, and the reviewer would rather see the two be separated so as not to dilute the focus on the WBG devices characterization efforts.

Another reviewer thinks the project is necessary to evaluate new devices, and that it seems like a logical approach to characterizing them and identifying system issues (e.g., gate drivers, control, etc.). A different reviewer found that the project has clearly defined goals and barriers to overcome, although the proposed air cooling system was not presented.

One individual, referencing the air cooled inverter, inquired as to how other components will be affected. He assumes with elimination of liquid coolant that more heat will be transferred into the rest of the module and increase the ambient temperature inside the module.

A reviewer raised the following four points: (1) testing more devices at a wide temperature range and various gate drive voltages will provide a valuable database in terms of understanding the issues and tradeoffs; (2) more work needs to be done at the system level and more specifically on the inverter design - so far, the focus has been on testing individual modules; (3) the issue of paralleling the devices still does not seem to be addressed; and (4) the air temperature specifications need to be well defined and compared against what practically can be available; there needs to be a number(s) equivalent to the 105°C number for liquid cooling.

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

One reviewer believes the project has made progress in the area of acquiring new prototype devices, but the extent of progress towards meeting thermal and power goals is difficult to assess at this time. Another remarked that there has been good progress, although an air cooled design has not been seen yet. A third reviewer indicated good progress, but added that comments on the approach need to be addressed and the issue of having suitable gate drives is dependent on another project. There should be strong coordination between both projects to make sure that the gate drivers will be available on time for testing the devices.

Still another reviewer thinks overall there has been good progress, but finds it hard to compare directly to the program objectives. The accomplishments to date are directionally correct, however.

In one reviewer's opinion, the assessment of devices should be performed more, for example, except for Ron, and switching power loss data, the temperature dependence of other parameters also are important, such as leakage current, blocking voltage, switching times (tr, tf) Capacitance $C_{iss}$, $C_{res}$, etc. The comparison of WBG devices and Si devices should be performed on power loss and thermal/temperature performance. Another issue that may be considered is the reliability of WBG devices, including the effects of poor interface structures, thermal cycling/power cycling, and short circuit capabilities; from a system point of view, what is the trade off device (die) and heat sink (cooler)?

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

One reviewer described the collaboration as outstanding for the device level but poor for the air-cooled inverter design portion of the project. Another commented that it seems almost all the work is being done at ORNL, and it was not clear what the role of the external partners was other than supplying the devices. A third reviewer was not clear on the University of Tennessee's contribution to the project, but found a good tie-in to component suppliers for an evaluation of SiC and GaN devices.

**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?**

In one commenter's estimation, the future goals appear to be reasonable. The goals will become more specific with future progress: complete thermal design and automated test facility. Another reviewer feels the plans are a logical extension of the work to date. This reviewer reported no significant barriers identified, except for the development of the wide bandgap materials themselves.

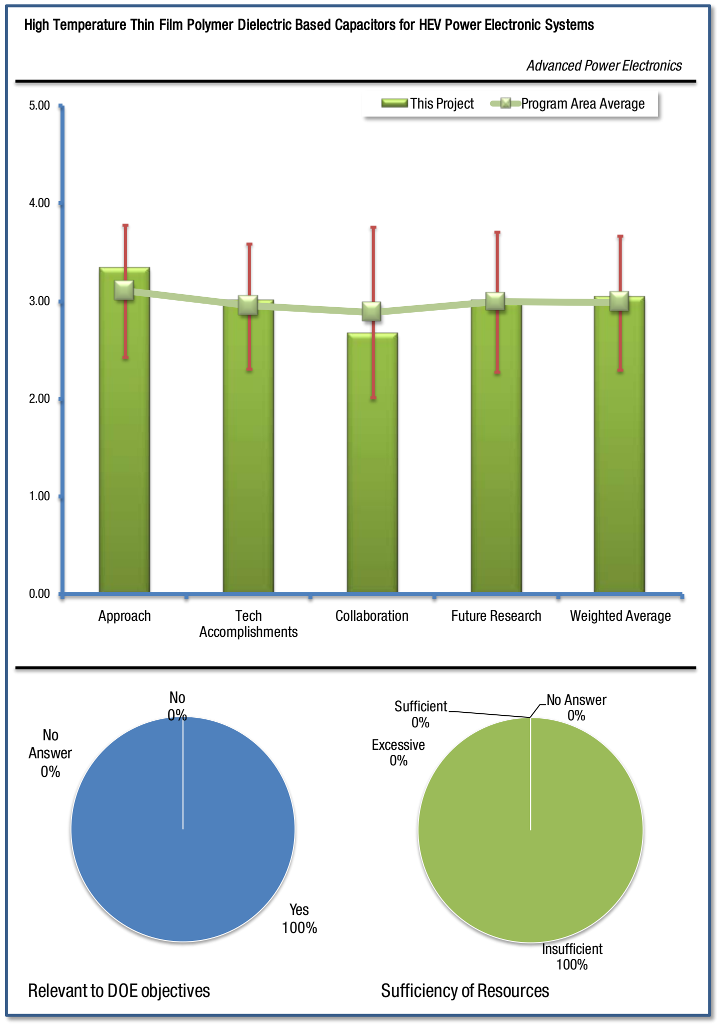
A reviewer reiterated that he would rather see the air-cooled inverter design project separated, as well as better collaboration with the tier 1 suppliers.

One person believes that testing more devices as well as finalizing the test facility and finalizing the inverter design all are steps in the right direction.

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

Six of the reviewers believe the resources are sufficient; one finds them insufficient.

## High Temperature Thin Film Polymer Dielectric Based Capacitors for HEV Power Electronic Systems: Shawn Dirk (Sandia National Laboratory (SNL)) - POSTER




**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?**

One reviewer stated that high temperature DC capacitors are needed for the development of a high temperature inverter, and that size needs to be reduced, too. Another remarked that high temperature capacitors are considered to be a key technology for enabling the use of 105°C coolant for vehicle power electronics, simplifying and reducing the cost of PE thermal management. The third reviewer said the synthesis of high temperature polymer films with a high energy density is a cost-competitive approach to developing DC-link capacitors. The composition and structure of the polymer should be designed to utilize a low cost monomer, to enable a graceful failure, and to improve manufacturing quality of the films.

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

A reviewer thinks polymer on foil may be a good solution, but notes that the manufacturability seems to be very difficult. He inquires about the investigator's confidence that it can be manufactured with a decent yield.

The second reviewer maintains that the creation of high temperature polymer film suitable for use as a capacitor dielectric is an entirely worthy goal. Working with a capacitor manufacturer that also has some film manufacturing capability also is attractive. Some technical barriers to high temperature capacitors, however, were not mentioned, such as leakage (specified dielectric stress & temperature) and ability to self heal.

The third reviewer believes an excellent job has been done to identify the requirements for developing a polymer film for capacitor applications to include cost, graceful failure, and film processing capability. It also is beneficial to investigate both solvent casting and melt extrusion for film processing due to concerns with the cost and quality for each method. It may help to identify the advantages or disadvantages of these film processing methods with respect to the copolymer that has been developed. It also would help to discuss what needs to be overcome before scale-up with respect to each method.

The reviewer continued that developing the capability to design and synthesize a copolymer with desired properties is a notable achievement, but what is unique in this effort is that lab-scale film processing techniques have been developed. This approach enables the ability to design the polymer for scale-up to film manufacturing, which is a common barrier due to the high cost of the film processing equipment and amount of material required. Moreover, the inclusion of nanoparticles is a good approach to improve the dielectric properties of the polymer film.

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

According to one reviewer, it is difficult to take a polymer candidate and create film that can be made into a capacitor. Such film must have few defects and be of uniform thickness. The suitability of a film for use in capacitors needs to be determined as early as possible in the development cycle to avoid work that may lead to an expensive dead end. Practical questions can be answered fairly early with small film quantities. Can it be metalized? Will it self heal at dielectric faults? What is the leakage current at constant dielectric stress and varying temperature? Some of these factors may be addressable early on small quantities of film that can be created in the lab. The reviewer believes the investigator as a chemist is doing good work, but would like him to be more understanding of what is needed for a real capacitor and thus be able to pursue more plausible polymer technologies looking for an ideal candidate as others are discarded when fatal flaws are found.

To a second reviewer, much progress has been made considering the amount of funding. It is a major challenge to develop a polymer dielectric for capacitor applications and an even greater challenge to scale it up for film manufacturing. The dielectric properties appear to be stable across the desired temperature range. It would help to obtain some DC or AC lifetime data for this dielectric material as a function of temperature. In addition, it would help to compare the dielectric properties to commercially available polymer films or even ceramic materials. Some information that would be good to see is the insulation resistance of the film as a function of temperature (required for DC link applications) and the voltage breakdown strength of the film.

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

One reviewer thinks there should be more information transferred regarding the dielectric requirements that are needed for capacitor manufacturers to produce practical and reliable capacitors; this reviewer was surprised at how little information apparently had been transferred to the investigator concerning exactly what was needed for such film to work, even to characterize the film that was made. The plot of Capacitance vs. applied voltage made no sense to this reviewer; it looked as though an instrumentation problem needed to be resolved.

Another reviewer found the collaboration with ECI to be significant because this company has the capability to evaluate the polymer film for scale-up. This company also has the capability to manufacture the film using both a prototype and an industrial scale system. In addition, they have state of the art equipment to metalize and wind the polymer into wound capacitors. If stacked capacitors are going to be pursued, it may be beneficial to look into the capabilities of capacitor manufacturers that focus on stacked devices (e.g. Paktron or Sigma Technologies).

It also may help to seek a collaboration to enhance the ability to characterize the dielectric properties under controlled environmental conditions.

The final reviewer asked who else within the industry is working on these types of capacitors, and whether there is any chance of collaborating 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?**

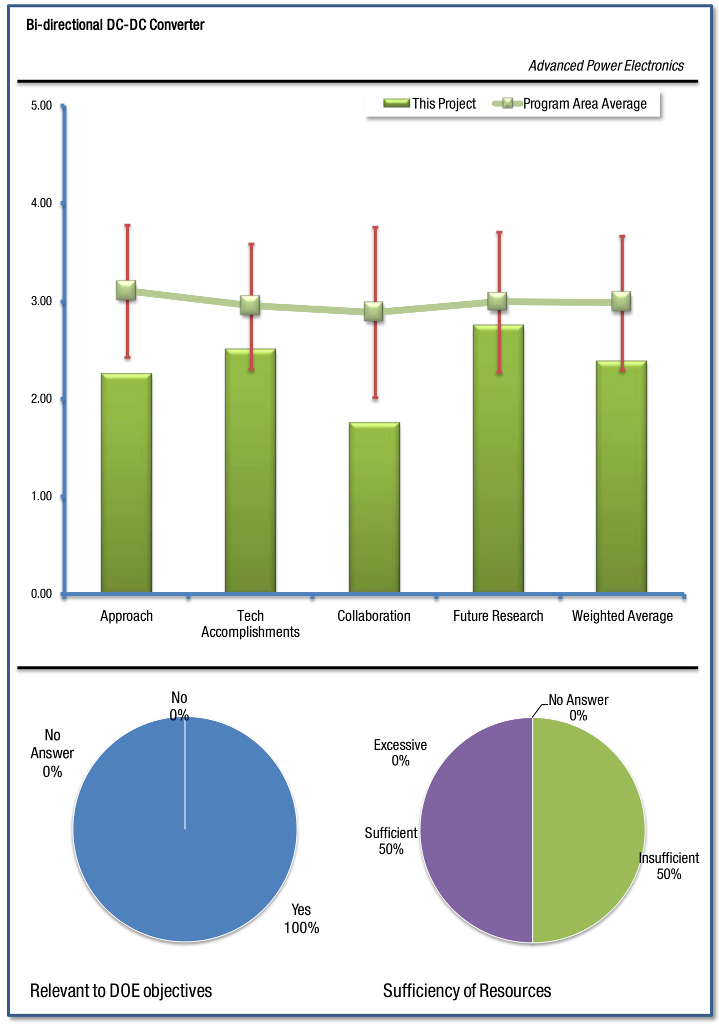
In one person's view, this was/is very low budget research. It may be that the available funds did not stimulate ECI to be more collaborative. The reviewer believes the budget stated for this project does not allow very much to be done, especially external to the research entity initiating an investigation like this. This, he maintains, is work that should be done and funded at an appropriate level. More information flow is definitely needed between the investigator and the capacitor manufacturer with whom he is working.

To another person, the incorporation of nanoparticles is an excellent approach to increase the energy density, but it also has been reported in the literature that it also can be utilized to improve the AC/DC breakdown strength, AC endurance, insulation resistance, and film processing capability. Functionalization of the nanoparticles is the right approach to obtain good dispersion within the polymer matrix. While there are many current efforts investigating polymer nanocomposites, this effort expands this field of research to investigate high temperature films. The collaboration with ECI is an excellent approach to investigate the film processing capability, which is essential since there is a current need to transfer information between polymer synthesis efforts and the film manufacturing efforts. The cross-linking of the film may improve the voltage breakdown strength or the Tg.

One reviewer asked how nanoparticle development is going to be handled, and whether it is a parallel development or whether the nanoparticle will only be investigated if the polymer does not work.

**Question 6: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?**
All of the reviewers believe the resources are insufficient.

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




**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?**

One reviewer stated that a bidirectional dc-dc converter allows energy transfer between two energy sources and between energy source and load. It helps energy management and improves the system level efficiency, and with proper design, it also can help extend the operating life of the energy source. Another remarked that a bidirectional DC/DC converter is another "must have gizmo" in PHEV/HEV/EV systems. The application to the two-battery energy storage system is justified, but not new. A third reviewer commented that this project supports the overall DOE objective of petroleum displacement by providing a low cost, high reliability, high power density converter that can be used to improve battery life in multiple EV platforms. The converter also meets DOE's 2015 goals of operation at 105°C inlet coolant and ambient temperatures.

For the final reviewer, conceptually the project sounds like a good idea, but he did not see any evidence showing how the cost and complexity of this system will pay for additional benefits. Nor did he see data showing the benefits.

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

A reviewer observed that Toyota uses the DC-DC boost converter to increase the voltage to around 500 volts; they just do not have a second high power density battery. How can 8 kW DC/DC be enough for full speed cruise?

According to a different reviewer, the technical approach, from a system perspective, is not new, and can be seen implemented in the L5 commercial product from Hymotion if one recognizes that the existing Prius NiMH battery is intended to play the role of the high-power-density battery. There appears to be an added element of novelty in the use of SiC normally on JFETs. Besides the fact that the initial design uses the wrong type of SiC switch for the topology used, it is not clear that any SiC switch is justified in that the cost/benefit ratio may not be favorable.

One reviewer thinks the approach should permit extended battery life and thus lower cost of HEVs along with improved EV-only range through the use of a dual battery system with a bi-directional DC-DC converter. This overcomes significant barriers to the acceptance of EVs. The approach to building or sourcing the actual converter, however, is not clear, as the focus appears to be on the vehicle system study.

One person offered three observations. First, multiphase circuit topology was mentioned, but the design was quite ordinary. The design did not adopt interleaving techniques, so the overall ripple current will be high. This requires an excessively high switching frequency to reduce the ripple. Otherwise, a large capacitor is needed to absorb it. The presentation indicates that 100 kHz is the planned switching frequency. This will result in poor efficiency. Second, the phase dropping concept for different load conditions is not new. The key is how to deal with dynamic changes, and this was not addressed in the presentation. Third, overall the presentation did not show any novelty or design improvement over the state of the art.

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

One reviewer would like to see more simulation test data to prove the concept's benefits.

To another reviewer, the presentation only showed vehicle level simulation results to justify the sizing of the dc-dc converter. This is not the core of the development, which should be the converter itself. In terms of sizing, different vehicles will have different requirements. The sizing issue should not be a major study as long as the converter can be scaled easily. In addition, the presentation did not really show any accomplishment. Key design elements such as inductor design for size and cost consideration, controller design that deals with dynamic load and operating mode changes, and semiconductor switch selection and packaging were not shown.

A reviewer remarked that aside from his lukewarm opinion of the project's relevance and technical approach, enthusiastic technical progress appears to be indicated from the presentation.

In another reviewer's opinion, significant vehicle system modeling has been completed for converter sizing along with a characterization of both Si and SiC converter component performance. This indicates that the barriers to the development of this technology will be overcome, although no prototyping or performance validation has been conducted.

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

Generally speaking, the responses were not very positive. One reviewer could not see how the university is involved and what input it has. Another did not see much collaboration, save for some data scavenging from the battery vendor, while a third indicated that the presentation did not identify the individual contributions of the team members, adding that it is unclear which work is being done by which organization. The remaining reviewer said the project appears to be a collaboration between US Hybrid and the University of Illinois-Chicago, with no other partners. The roles of each of these two institutions are not clearly spelled out.

**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?**

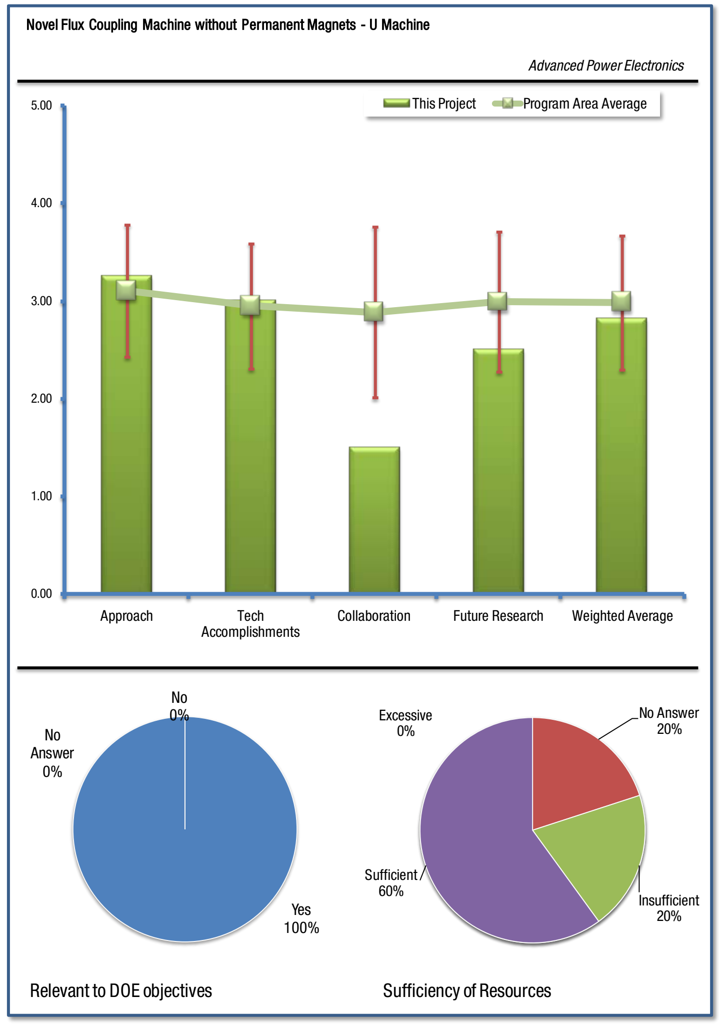
In one's view, the project management seems to know what they need to do to complete the project. Since this is primarily a modestly complex engineering project, the going-forward research plan seems adequate. According to another reviewer, full performance validation of the production prototype high density power converter for efficiency at junction temperature, power density, specific power, and bandwidth are planned. These elements will demonstrate sufficient capability of the converter to show that it can be used to provide the advantages outlined in the vehicle system study of Phase I.

One respondent noted that while high switching frequency and high current loop bandwidth were mentioned, the issue of how to maintain high efficiency was not addressed. The 20-kHz current loop bandwidth was targeted, but the sensor conditioning and analog-to-digital bandwidth limitation and sample-and-hold delay were not addressed. How practical is this bandwidth and why is it necessary?

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

The responses were evenly split; two believe the resources are sufficient, and two believe they are insufficient.

## Novel Flux Coupling Machine without Permanent Magnets - U Machine: John Hsu (Oak Ridge National Laboratory (ORNL)) - POSTER




**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 person feels this work could lead to a low cost traction motor, which will improve the fuel economy of HEVs and could be applied to pure EVs. To another reviewer, advanced motor design and development that promises to increase constant power speed range and power factor can potentially reduce volume and weight at a minimum. By itself, this will reduce fuel consumption. Yet another reviewer stated merely that the project is consistent with DOE objectives, a fourth said it is targeted to low cost motors, and a fifth said it strives to eliminate PMs.

**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 described the approach as a good start, and another said it is a very well organized and structured project with a focus on key novel magnet-free design with improvements over IPM performance and power density. The concept of using the stator frame to carry the exciter current is highly novel and appears to provide tangible benefit to the overall motor performance. If PM materials can be eliminated, there is potentially a measurable reduction in motor cost with regard to conventional PM machines.

One person remarked that the principal investigator has extensive machine design experience and understands the limitations of current electric motors. This design seeks to overcome the barriers of high magnet cost by removing them. The concept of a statically excited field would motor is not new, but this implementation is novel. Placing the excitation coil in the end bell helps reduce overall length. If the investigator can overcome some obstacles, it will provide effective field weakening and improved low speed torque.

Another reviewer said a nice investigation has been carried out, but there are still doubts about the feasibility of the proposed approach. The power density is questionable. The last reviewer said there is insufficient information to assess the approach.

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

One reviewer thinks the FEA results look promising, while another opined that although the analysis looks promising so far, there are still many cost and mechanical design issues ahead. This reviewer said he will be more confident when a working prototype is built and tested. Similarly, another reviewer noted that so far the work is on paper. Even though it has demonstrated some advantages, more work is needed to further demonstrate the technology.

A reviewer feels there is insufficient information to assess the accomplishments and progress. In another's view, thorough modeling results have reasonably mapped out the relevant design space for this novel design. This particular reviewer would like to have seen some thermal modeling data to accompany these results and benchmark the baseline design in terms of winding and flux path heat rejection.

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

One reviewer feels there is insufficient information to assess the collaboration with other institutions, while another believes there is no collaboration at this time. A third thinks this effort is internal to ORNL, and a fourth maintains that the work needs to be connected to industry, for three reasons: (1) industry can provide feedback on the technology and whether it is feasible (performance, manufacturability, etc.); (2) for eventual commercialization of the technology; and (3) to hasten the development process.

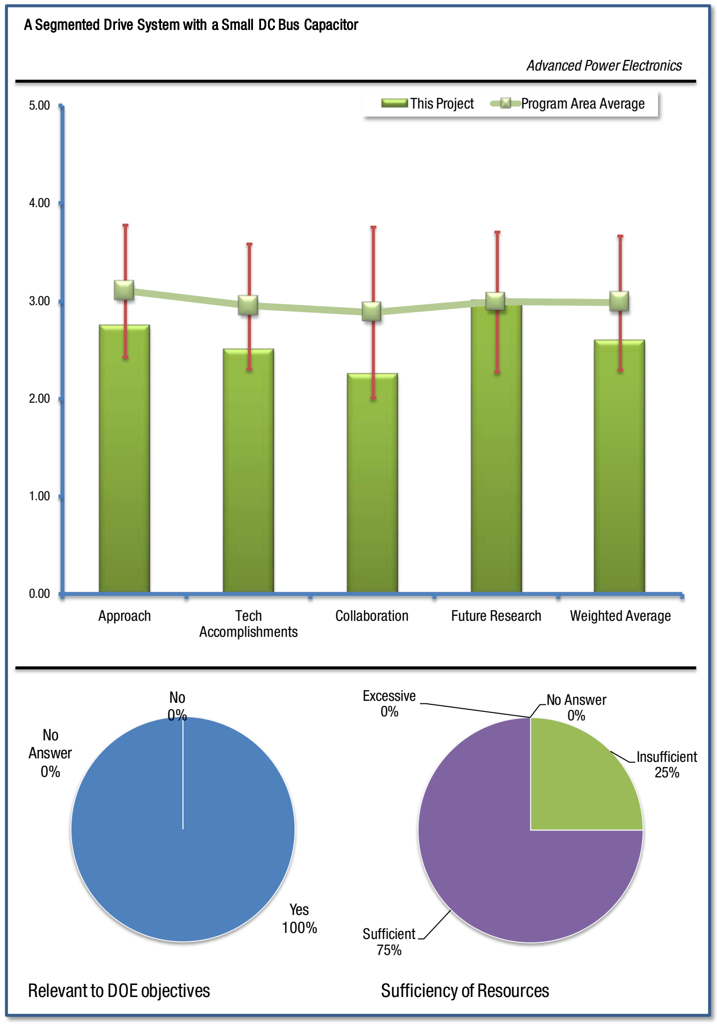
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

One reviewer merely said it is hard to predict the outcome, another noted that the investigator plans to build hardware next year, and a third indicated that while the project may be able to overcome the barriers, a prototype is urgently needed to validate the claims. Another reviewer found a good plan to evaluate manufacturing cost, structural design, and torque issues.

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

Four reviewers responded; three think the resources are sufficient, and one finds them insufficient.

## A Segmented Drive System with a Small DC Bus Capacitor: Gui-Jia Su (Oak Ridge National Laboratory (ORNL)) - POSTER




**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?**

One reviewer believes the project, if successful, will enable capacitor downsizing, while another thinks it could provide significant improvements in package volume and inverter cost. According to yet another, the project supports the overall objective because modifying the circuit topology to reduce the ripple current reduces the demand for the DC link capacitor, which will enable a lower weight and volume. This reviewer wonders, though, what the benefits are based on the cost, reliability, and complexity of the modified circuit topology.

To another reviewer, this is a new start and very little technical information is available. Information is under patent review. The presentation, however, suggests it is addressing the goals.

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

One person said he did not learn enough to know the concept, and another thinks there is insufficient information. According to the third respondent, the simulation data looked good but the circuit topology used in the simulation was not clear. It appeared that a higher switch rate was utilized, but it was unclear how this would affect the capacitor (e.g., parasitic inductance and DF).

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

One reviewer asserted a need to learn more and understand details of the work so as to be able to make judgments. A second reviewer said it is too early to tell, and a third simply reiterated his view that this is a new start. The fourth reviewer noted that due to a patent pending, not a lot of information was presented to gain an understanding of the approach taken. It would help to evaluate the efficiency and cost of the modified circuit topology versus that gained from decreasing the size of the capacitor. Also, what are the new requirements for the capacitor using this segmented drive system, and can current capacitor technology be utilized?

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

Only two responses were provided; one reviewer stated that collaborations were not indicated, and the other said that although it is very early, he would like to see some collaboration.

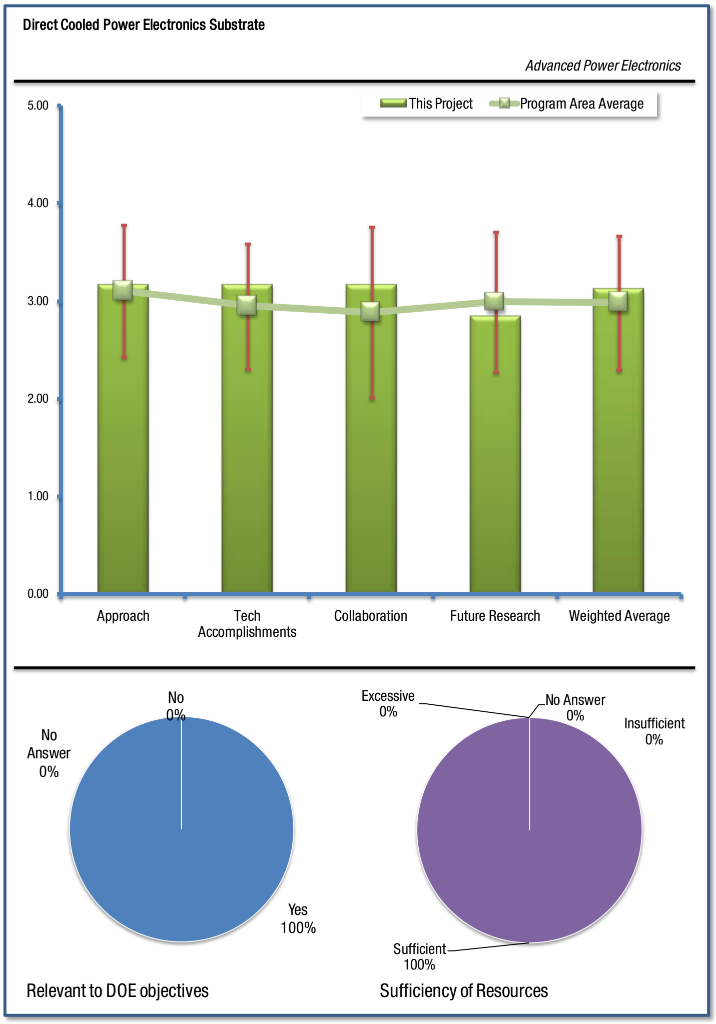
**Question 5: Has the project effectively planned its future work in a logical manner by incorporating appropriate decision points, considering barriers to the realization of the proposed technology, and, when sensible, mitigating risk by providing alternate development pathways?**

The lone respondent said it will be beneficial to discuss the circuit topology in the future and to verify the simulation with the construction and testing of the hardware.

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

Three reviewers think the resources are sufficient; one believes they are insufficient.

## Direct Cooled Power Electronics Substrate: Randy Wiles (Oak Ridge National Laboratory (ORNL)) - POSTER




**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?**

One reviewer stated that the project can enable a higher coolant temperature, another noted that the technology, if successful, will be an enabler for meeting the high temperature and power density targets for the power converter, while a third indicated that direct cooling can lead to smaller packaging, reduced mass, and higher power densities; with a proper level of integration, it also should support reduced cost.

To one reviewer, the ability to embed effective cooling channels into a Direct Bond Copper (DBC) substrate would be a great step towards reducing the thermal resistance between the power semiconductor devices and the coolant. Such a reduction could enable higher power ratings for a given inverter, or the direct use of 105°C coolant with silicon- based devices. Achieving one or both of these goals could significantly drop the price of existing HEV and PHEV solutions, which would enable petroleum displacement due to the higher levels of fuel economy associated with these 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?**

One reviewer said he likes the focus. Another thinks the approach is well defined and clearly presented, and that the objective demonstrates an understanding of fundamental engineering and manufacturing (sealing) issues that are to be overcome. A third reviewer believes the proposed technical approach systematically is trying to address many of the challenges, although it is not clear who is going to build the whole inverter. More focus is needed at the system level.

One reviewer identified a key concern that may require some investigation -- the stability of these assemblies relative to thermal shock. This already is an issue with DBC substrates that use thick metal, and some analysis should be conducted to evaluate the reliability of this technology with respect to this issue.

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

One person found the simulation results to be promising. Another reported good technical progress, but noted the test results are the key to validating the project's merits. Similarly, a different reviewer indicated that the key phase will be to see how the test results match expectations. According to yet another, the technical accomplishments are significant and appropriate, the investigators have identified promising designs, and the technical accomplishments are experimentally validated.

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

Each of the three respondents gave a positive assessment. One stated that the collaborative efforts are clearly identified in the presentation. Another found that there is a lot of collaboration with external partners in terms of manufacturing the devices. The third commenter remarked that the only way to get better collaboration would be to include a Tier 1 supplier that understands the automotive environment better and could provide a better systems look.

**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 believes the future work is well reasoned, and that testing the hardware clearly is the greatest goal. Another thinks moving to the marketplace may require the involvement of other partners. To the final respondent, the proposed future work is logical and systematic. This reviewer suggests that the project team keep an eye on what other teams are doing (especially the Delphi project) and benchmark its progress versus other technologies.

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

All of the reviewers believe the resources are sufficient.