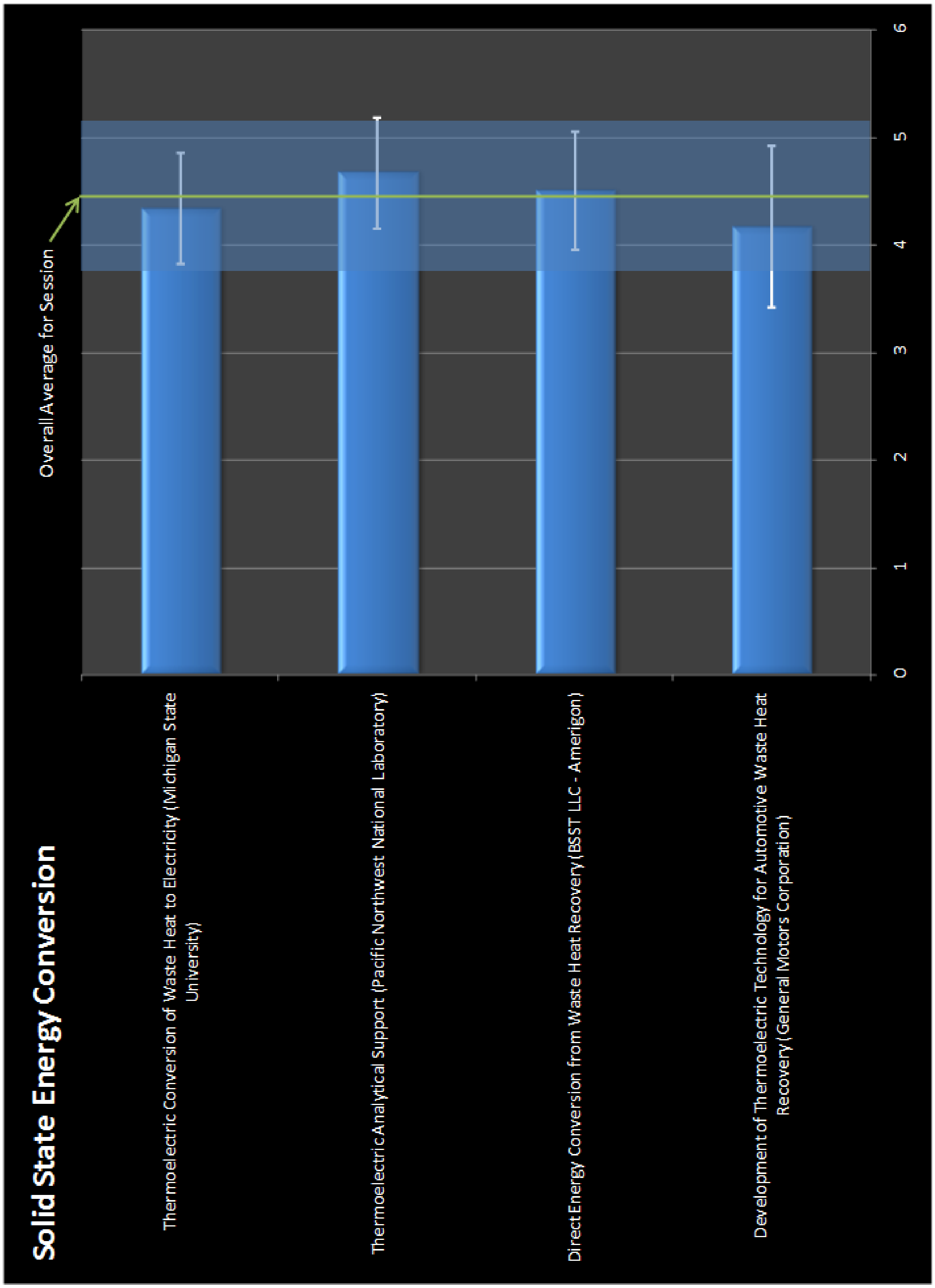
6. Solid State Energy Conversion

Introduction

The Solid State Energy Conversion activity focuses on developing advanced thermoelectrics for converting waste heat from engines into useful energy (e.g., electrical energy) to improve overall vehicle energy efficiency and reduce emissions. Effective use of waste heat from combustion engines would significantly increase vehicle fuel economy. In current production passenger vehicles, roughly over 70 percent of the fuel energy is lost as waste heat from an engine operating at full power. About 35 to 40 percent is lost in the exhaust gases and another 30 to 35 percent is lost to the engine coolant. There is an opportunity to recover some of the engine's waste heat using thermoelectric materials that will convert it directly to electricity for operating vehicle auxiliaries and accessories. The goal of this activity is to develop advanced thermoelectric technologies for recovering engine waste heat and converting it to useful energy that will improve overall engine thermal efficiency to 55 percent for Class 7 and 8 trucks, and 45 percent for passenger vehicles while reducing emissions to near-zero levels.

In this merit review activity, each reviewer was asked to respond to a series of six questions, involving multiple-choice responses, expository responses where text comments were requested, and one numeric score response. 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 pictorial form in eight graphs as the last page of each project, and the expository text responses will be summarized in paragraph form for each question. A table and graph presenting the average and standard deviation for each project relative to the overall average and standard deviation for this session is presented below.

Page	Project Title and Principal Investigator	Project Average Score	Project Score Standard Deviation
6-3	Development of Thermoelectric Technology for Automotive Waste Heat Recovery (Jihui Yang, General Motors Corporation)	4.17	0.75
6-7	Direct Energy Conversion from Waste Heat Recovery (Lon Bell, BSST LLC - Amerigon)	4.50	0.55
6-11	Thermoelectric Analytical Support (Terry Hendricks, Pacific Northwest National Laboratory)	4.67	0.52
6-14	Thermoelectric Conversion of Waste Heat to Electricity (Harold Schock, Michigan State University)	4.33	0.52
	Overall Session Average and Standard Deviation	**4.42**	**0.58**


Solid State Energy Conversion
Overall Average for Session
0
1
2
3
4
5
6
Thermoelectric Conversion of Waste Heat to Electricity (Michigan State University)
Thermoelectric Analytical Support (Pacific Northwest National Laboratory)
Direct Energy Conversion from Waste Heat Recovery (BSST LLC - Amerigon)
Development of Thermoelectric Technology for Automotive Waste Heat Recovery (General Motors Corporation)

Development of Thermoelectric Technology for Automotive Waste Heat Recovery (Jihui Yang of General Motors Corporation)

Reviewer Sample Size

This project had a total of 6 reviewers.

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

The reviewers had some disagreements regarding the program's goals. One reviewer commented that waste heat recovery in general is a good approach to increase fuel economy of vehicles. Another person stated that the objectives of this project (finalizing material selection, completing the initial design for the exhaust waste heat recovery, and identifying manufacturing processes for thermoelectric modules) are realistic, right on the mark, and well-aligned with DOE's objectives of petroleum displacement. One reviewer simply indicated that this activity does comply with DOE's goal of 10% improvement in fuel efficiency with regard to waste heat recovery for vehicle applications.

Others were less enthusiastic. One responder noted that the goal of the SSEC program is to reduce petroleum consumption by 10% through state power generation, but the goal of this activity is only a 3% improvement. The person adds that the vehicle platform chosen somewhat limits their ability to meet program goals. Another person noted that a reduction in parasitic loads on a vehicle can reduce cycle-average and real-world fuel consumption, adding that no requirement for the total amount of fuel savings is requested and there will certainly be some savings. The person adds that it is highly unlikely that this approach can save 10% fuel economy in any reasonable real-world cycle-averaged scenario. One final commenter stated the objective of a 10% increase in fuel economy on a designated vehicle platform is understood. The group believes they can deliver at least a 3-4% increase using a FTP cycle and more in a real world driving cycle. The reviewer adds that the overall system cost of $1 per watt is a target and seems to be well-accepted. This person was also unsure about the vehicle platform, noting that GM's program is targeting a large SUV as the platform vehicle of choice. GM stated that space requirements and heat loss are advantageous in this vehicle for an everyday non-commercial vehicle. A large truck platform could also be investigated in tandem with the SUV platform.

Question 2: Are the goals of the project technically achievable? Have the technical barriers been identified and addressed? Is the project likely to overcome those technical barriers? Please comment on the project's strategy for deployment of technologies.

Respondents had mixed reviews regarding the project's strategy. One person indicated that the group recognizes the technical hurdles (uncertainty of materials performance, difficulties in module design and integration) and systematically addressed and overcame them with an excellent plan. Another person felt that there was a good strategy in place to accomplish the task. Similarly, another indicated that the barriers are correctly identified and goals are achievable, adding that, with 37 presentations and publications, it seems that the team has made progress. They should investigate recent work by Honda and Toyota in the same area, as these groups have claimed about 5% fuel economy increase (or 500W recovery of electricity), while this project has 350W or 3% gain.

Another respondent felt that specific project goals were not defined in the presentation. They felt that the group had done a good job identifying manufacturing barriers, but other barriers (mechanical, thermal etc) were not discussed in any detail. Further, one person added that the project goal of 10% increase in fuel efficiency is not likely, but significant progress can be made. The barriers have been identified and a lot of work on performance and mechanical testing of the materials and modules is in progress. The PI's have a strong team in place to address these barriers, and they understand the overall goals of the program very well. There has been a lot of emphasis on new materials development at about a 50% level in the program according to the PI. They have down-selected a material about which they were unwilling to disclose the details. It is recommended that they focus their efforts much less on the materials and more on the device development and implementation in the next phase. They have stated that this is their goal with a significant shift towards this end in Phase II. They should keep a small effort going in new materials development of already very promising materials. Module design should not be a problem for GM. They have a very good chance of having a prototype device on a vehicle very soon. At no point in the review did the PI discuss GE's role in this project and they were not very specific on the details of what they have done or were planning.

Question 3: Characterize your understanding of the technical accomplishments and progress toward DOE goals: please state the reasons for your assessment.

One reviewer noted that the team spends a majority of their efforts on advanced materials development. Most of this program appears to be focused on achieving a breakthrough in ZT for power generating materials. They still have not discussed in enough detail how to overcome the other engineering, manufacturing, and market issues with the technology. Similarly, one person added that the project is on track with the proposal goals; however, without knowing the details of the approach (which are proprietary), it is hard to justify the exact progress. Another respondent felt the same way, stating progress of this program is difficult to gauge based on limited details in presentation. The group claims to have made significant materials advances and finalized system design, but no evidence given.

One person stated that the team has developed and down-selected the materials, decided on a vehicle platform, performed a cost analysis, and is now in the process of developing a prototype TE generator. Another stated GM has demonstrated a willingness to work on the task as well as collaborate with other organizations, such as Oak Ridge National Lab.

One final reviewer commented that the group had shown impressive accomplishments overall, particularly the following: (1) selection of low $/W materials with reasonably high ZT; (2) establishing high-temperature thermo-mechanical property data; (3) completion of testing facility; (4) completion of excellent design for exhaust waste heat recovery (350W, 3% urban/highway fuel economy improvement), which could yield 4% heat conversion efficiency after integration; (5) excellent team effort and coordination (strongest team); and (6) an impressive number of publications, talks and patent applications. This final reviewer added that this project has shown the highest overall output.

Question 4: What is the likelihood that the project team will move the technologies toward or into the marketplace? Please state the reasons for your selection.

Results for technology transfer were, in general, positive. One reviewer stated that the team already has a large OEM and this team has applied for several patents, adding that it should be easier for them to transition this technology than any of the other teams. In the same respect, one person commented that GM also recognizes all the barriers and therefore will be able to carry the project successfully. Another response stated that, with their first-rate output this year and their plans to finalize TE waste heat recovery subsystem design and subsystem prototype construction next fiscal year, the schedule for technology transfer and market transformation should be on target.

Others were less sure, with one reviewer stating that, without knowing the detailed technology, it is hard to know whether the technology will be marketable. Another person stated that some form of this technology could migrate into production if the cost and packaging targets in the program are met, adding that it is unclear right now if the team has an approach that will allow commercialization. Lastly, one person (similar to comments above) felt that leadership by GM makes it likely that any technological advances will be commercialized, but added there weren't enough details available to assess its potential.

Question 5: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

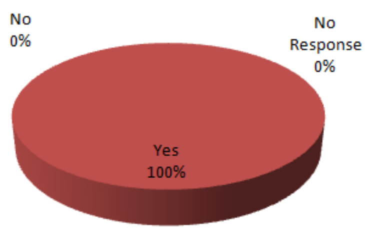
Multiple reviewers felt that the available resources seem to be sufficient, with one person adding that the team may consider reallocation to other aspects of engineering the TE module and vehicle systems. Another person noted that the team also has access to Michigan state university and DOE laboratories, while someone else commented that collaboration with ORNL is an excellent way to achieve milestones in a timely manner. Another person stated that the team has sufficient resources available in terms of materials synthesis and characterization as well as device modeling and development, adding that they also have access to all of GM's capabilities in design and manufacturing. One final person stated that they have received large amounts of funding, but added that milestones were not clearly defined, making this difficult to assess.

Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.

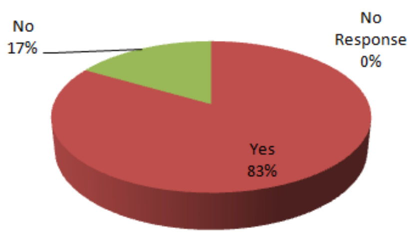
There were no expository comments for this question: refer to the graphic on the next page for this project's summary score.

Project: Development of Thermoelectric Technology for Automotive Waste Heat Recovery

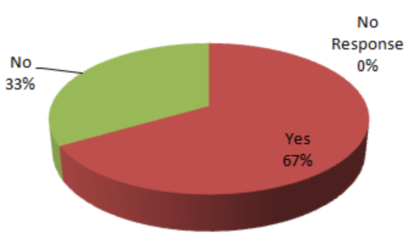
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



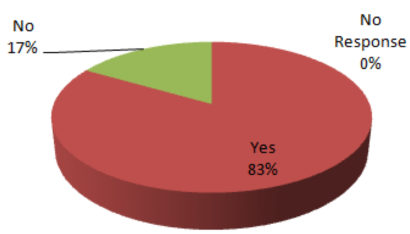
Question 2a: Are the goals of the project technically achievable?



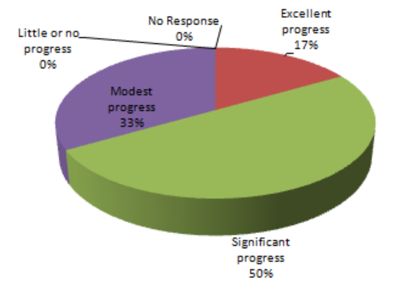
Question 2b: Have the technical barriers been identified and addressed?



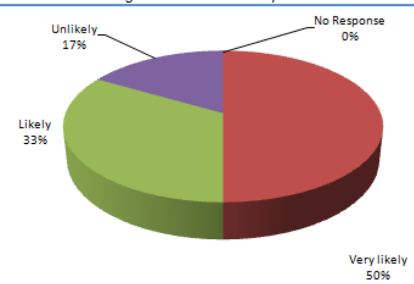
Question 2c: Is the proposed work likely to overcome technical barriers?



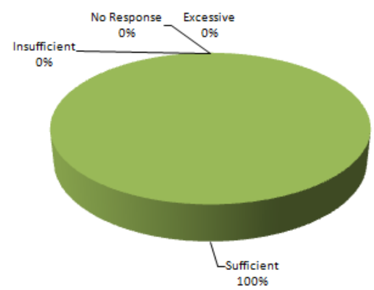
Question 3: Characterize the technical accomplishments and progress toward goals.



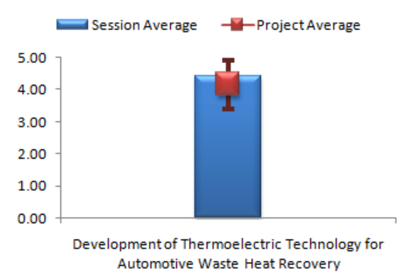
Question 4: How likely is the project team to move technologies into the marketplace?



Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



Question 6: Overall Rating



Direct Energy Conversion from Waste Heat Recovery (Lon Bell of BSST LLC - Amerigon)

Reviewer Sample Size

This project had a total of 6 reviewers.

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

There was some disagreement among the reviewers here. One person began by stating that the reduction in parasitic loads in vehicles can reduce cycle-average and real-world fuel consumption. There is no requirement for the total amount of fuel savings is requested, and there will certainly be some savings. The person added, however, that it is highly unlikely that this approach can save 10% fuel economy in any reasonable real-world cycle-averaged scenario. Somewhat more positively, another reviewer noted that the goal of the SSEC program is to reduce petroleum consumption by 10% through state power generation. The goal of this activity is consistent with DOE objectives. Modeling has shown up to 8% efficiency improvements, but this was under very favorable conditions; most conditions only showed 2-3% gains.

One response stated that the objective of a 10% increase in fuel economy on a designated vehicle platform is understood. The group did not actually state their overall increase in fuel efficiency to the best of the reviewer's recollection.

Others were more positive, with one person stating that waste heat recovery in general can increase the fuel economy of vehicles, and therefore it is in line with DOE's overall goals. Another added that BSST's TE power generator will be used to improve fuel efficiency of the vehicle, while a final person commented that the group's objectives of improving fuel efficiency by 10% and creating a path to commercialization exactly align with DOE's objectives of petroleum displacement. There is some discrepancy amongst the responses.

Question 2: Are the goals of the project technically achievable? Have the technical barriers been identified and addressed? Is the project likely to overcome those technical barriers? Please comment on the project's strategy for deployment of technologies.

One person commented that BSST has a good approach in developing their TE generator, but felt that a more detailed description of how to monitor and control the hot side of the TE generator is needed. Another reviewer stated that it is really unclear that the economic requirements of a light-duty application will be viable in the North American marketplace, adding that the team has started with a good approach to assessing performance against the durability requirements of the light-duty vehicle cycle. However, it is unclear if these barriers can be overcome in the time period that the program predicts, and, longer term, it may be more practical to overcome the engineering and technical barriers. One other person felt that the project team showed a sound strategy to overcome various technical barriers by developing new system architecture and using system modeling approach.

Another reviewer noted this was the only program to specifically address using segmented TE's, and that this seems to be the only feasible approach to achieving program metrics using materials available today. Thermal issues have been identified and well addressed, mechanical issues less so. More mechanical modeling of segmented devices is required.

Lastly, one reviewer provided the following points: a.) A project goal of 10% increase in fuel efficiency is not likely, but significant progress can be made. b.) The barriers have been identified. A lot of work is in progress on development of the materials, the modules and heat exchangers. c.) The PI's have a strong team in place to address these barriers. d.) The PI's understand the overall goals of the program very well. This is a very strong team. They have partnered with Visteon for development of the power electronics and with several universities to continue to develop higher efficiency materials. However, this is not infringing on the progress of a prototype development. The reviewer added that there is a tremendous amount of expertise in the heat exchanger and thermal management aspects of this project, but there is not a lot of effort on investigating and modeling the effects of mechanical properties. They also are imposing non-rigid constraints. This is a good idea, especially for the initial prototype. They have a very good chance of having a prototype device on a vehicle very soon. It would have been advantageous to understand BMW's role and contributions to the project in more depth.

Question 3: Characterize your understanding of the technical accomplishments and progress toward DOE goals: please state the reasons for your assessment.

Feedback was generally positive here, with one reviewer noting that their presentation showed that BSST has been making significant progress in a timely fashion. Another said that this team has adapted well to changes required by an economically feasible system. They have been very open about their program, technical requirements, and modifications that the team has had to make during the program to meet their assumptions. One other person noted that the team has developed and down-selected the initial materials, and they have decided on a vehicle platform. They have a lot of expertise in incorporating their devices into vehicles. This person added that the group is in the process of developing a prototype TE generator and appear to be further along than the other teams.

One reviewer commented that the barriers are identified, and some work has been done to overcome these barriers. The group has worked with Visteon to design power electronics for maximum power tracking. Another noted good progress on thermal design through new system architecture. Heat exchanger designs are crucial to system level performance and BSST has developed architectures to address this. Performance of hot gas heat exchange still needs to be verified. Thermal cycling work using BiTe was good, but is just a start toward determining reliability of this concept. There is a strong system-level thermal model based on realistic (average) ZT, but still need system-level demonstration of segmented devices.

A final reviewer remarked that the group's overall achievements are impressive, including: a.) New architect to enable high efficiency power conversion and reduce TE material usage; the module size appears to be in good progress and on schedule, b.) Encouraging model results for optimization of system performance, and c.) Good team effort.

Question 4: What is the likelihood that the project team will move the technologies toward or into the marketplace? Please state the reasons for your selection.

Comments from the reviewers, in general, were very positive. One commented that it is possible to move to the market, adding that the 500W of power generated are a good scale of power generation. Another person felt that some form of this system can be migrated into the marketplace based on the data presented, and this team seems to have the best chance of implementing some form of this technology into the marketplace. Adding to this, one reviewer indicated that technology development shows good progress, and that the team has shown a good FY 2008 work plan, which includes the testing of a full scale system by year-end. Technology transfer should be possible and within reach.

Others commented on industry partners, with one person stating that partnership with BMW and Visteon increases the likelihood that advances will be commercialized, but added that the use of segmented TE's may drive cost to prohibitive levels. Another noted that BSST has been working on their design for several years, and its technology has been actively tested by BMW. One final reviewer stated that the team has already done this with the BSST climate-controlled seat and should have no issue with moving the TE generator forward. They have partnered with BMW and selected a vehicle platform for installation. They may be the furthest along in terms of integrating a TE generator on a vehicle platform than any of the other teams.

Question 5: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

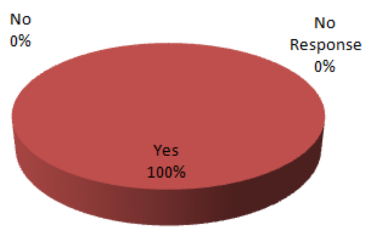
Most reviewers stated that the current resources and allocation seem to be sufficient for the team to meet its objectives / proposed activities, with one person noting the collaborations with Virginia Tech and Ohio State, along with various patents and publications. Another reviewer stated that these collaborations with BMW, Visteon, and universities will provide sufficient resources for the project. One final reviewer indicated that the team has sufficient resources available in terms of materials development into devices with elaborate configurations for the heat exchangers, and they are well equipped with respect to device modeling and development. They have partnered with several other institutions for new materials development and with companies for power electronics development.

Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.

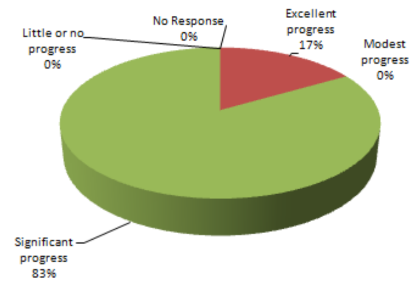
There were no expository comments for this question: refer to the graphic on the next page for this project's summary score.

Project: Direct Energy Conversion from Waste Heat Recovery

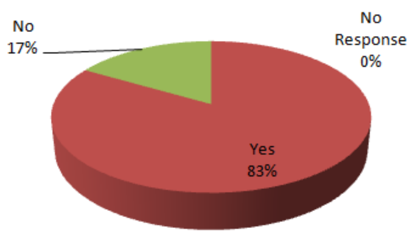
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



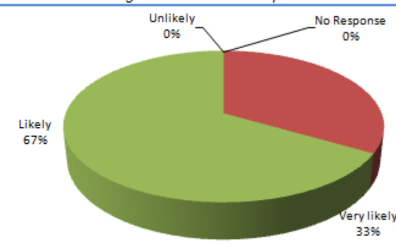
Question 3: Characterize the technical accomplishments and progress toward goals.



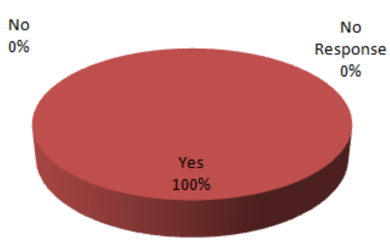
Question 2a: Are the goals of the project technically achievable?



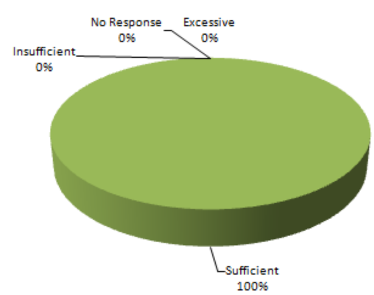
Question 4: How likely is the project team to move technologies into the marketplace?



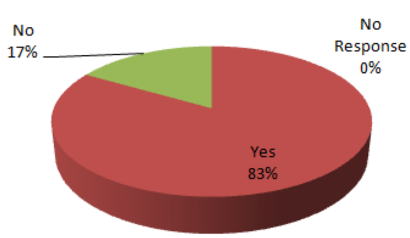
Question 2b: Have the technical barriers been identified and addressed?



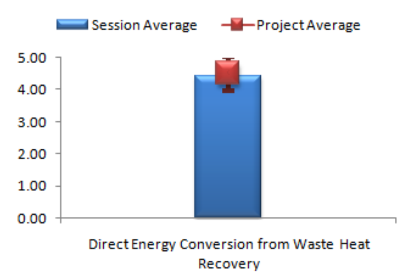
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



Question 2c: Is the proposed work likely to overcome technical barriers?



Question 6: Overall Rating



Thermoelectric Analytical Support (Terry Hendricks of Pacific Northwest National Laboratory)

Reviewer Sample Size

This project had a total of 6 reviewers.

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

Responses were generally positive in this section, with multiple reviewers noting that the project objective (technology that increases vehicle fuel economy by up to 10%) supports the DOE's petroleum displacement objective. One person stated that the validation of advanced low-dimensional TE materials is critical to determining their commercial viability, while another commented that it is necessary to have this type of Thermoelectric Analytical Support. One final respondent added that this team is acting in an Advisory role and understands the goals of the project completely.

Question 2: Are the goals of the project technically achievable? Have the technical barriers been identified and addressed? Is the project likely to overcome those technical barriers? Please comment on the project's strategy for deployment of technologies.

Multiple reviewers voiced support for this aspect of the program, with one person stating that this activity will certainly be needed to ensure that DOE projects are monitored and evaluated properly. Another indicated that the group addressed the previous reviewer's comments and that all technical details are on track. One person commented that, in terms of the advisor and "watchdog" role that PNNL plays, they are performing a vital service to this DOE program. Another reviewer indicated that validating materials claims is important, so developing standard experimental techniques is important for the success of this program.

One response expressed some skepticism, stating that it is optimistic to assume that the required TE will be met in the near-term. Some of the measurements and models proposed will require extensive development work. The person added that it is unclear whether the resources exist to meet these goals. One final reviewer commented on the sound technical approach in integrating TE system-analysis with materials & testing R&D, and that it was important to promote industry/government agency collaboration and interactions.

Question 3: Characterize your understanding of the technical accomplishments and progress toward DOE goals: please state the reasons for your assessment.

Multiple reviewers commented on the strengths of the program. One person commented that the PNNL team works with all other PI's in order to coordinate the overall goals of the program, while another stated that great flexibility has been shown in the ability to support all aspects of this work. Another reviewer stated that PNNL provides support to WHR&U in terms of project evaluations, thermal electric analysis, testing, and new initiatives. One response added that Terry brings a strong benefit to the team by providing technical guidance and validating performance, while another commented that the presented graphs and analysis suggest that the program is on the right path to achieve the goals.

One final reviewer stated that the group: (1) Did a great job as the project leader of coordinating and developing advanced technologies to reduce fuel consumption and improve vehicle fuel economy, (2) Did excellent analysis to help both power generation and cooling systems (including integrated TE system analysis, device specific analysis, project-specific analyses, etc), (3) Showed great coordination for the important task of Si/SiGe thin film material/properties validation, and (4) Demonstrated encouraging research results in collaboration with ONAMI.

Question 4: What is the likelihood that the project team will move the technologies toward or into the marketplace? Please state the reasons for your selection.

Many reviewers indicated that this question was not applicable for this type of support and that no demonstrated ability for advanced materials was available. Two reviewers added that the PNNL activity provides crucial guidance and tremendous expertise to assist the PI's in this endeavor, if tech transfer were to occur. One final person agreed, adding that, because of various successful collaborations (with PNNL/industry/university, and also government/industry) on materials, devices, and systems and testing, technology transfer into the market place will be highly possible.

Question 5: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

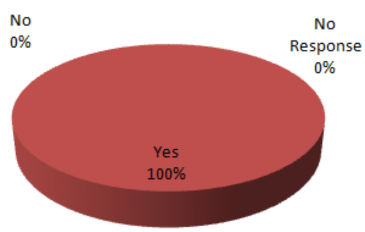
Multiple reviewers felt that the stated objectives seem to have enough resources, with one person adding that many questions raised in this work will require additional funding and investigation. Access to the PNNL database would help others in the US industry to develop internal studies, and mechanisms to obtain this work should be put in place. Other reviewers indicated that higher funding to PNNL to address cost and system analysis would improve the program, and that the current funding for these types of collaborations and support might not be sufficient. Another person added that the group gets a small amount of resources, but produces a lot of output. One other response stated that the team has sufficient resources available in terms of the requirements of the program. However, in the reviewer's opinion they are under-funded for their efforts and the role they play in the overall potential success of this program. More resources should be provided to the group, especially in the area of materials evaluation and validation. This seems to be an ever-occurring problem in many programs. However, the claims of the Si-SiGe quantum wells have to be resolved once and for all. Overall, this effort seems under-funded.

Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.

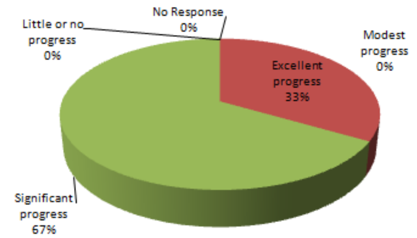
There were no expository comments for this question: refer to the graphic on the next page for this project's summary score.

Project: Thermoelectric Analytical Support

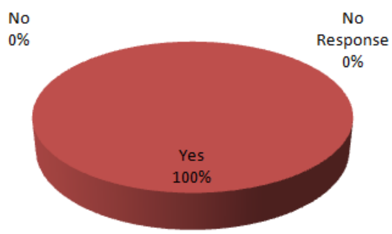
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



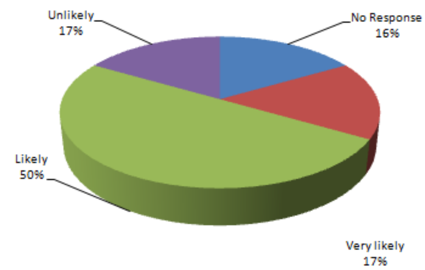
Question 3: Characterize the technical accomplishments and progress toward goals.



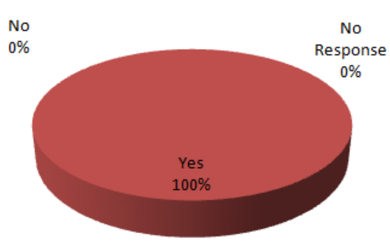
Question 2a: Are the goals of the project technically achievable?



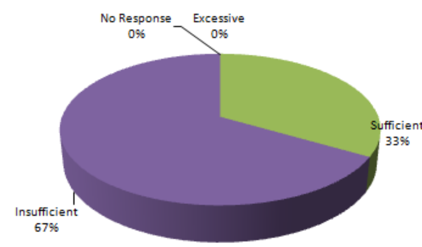
Question 4: How likely is the project team to move technologies into the marketplace?



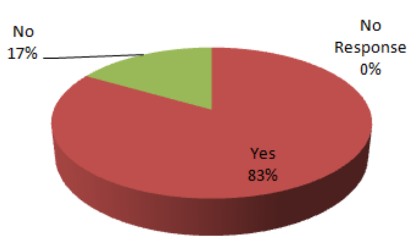
Question 2b: Have the technical barriers been identified and addressed?



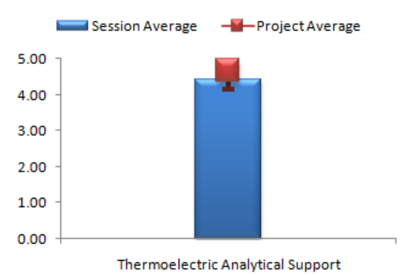
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



Question 2c: Is the proposed work likely to overcome technical barriers?



Question 6: Overall Rating



Thermoelectric Conversion of Waste Heat to Electricity (Harold Schock of Michigan State University)

Reviewer Sample Size

This project had a total of 6 reviewers.

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

Multiple reviewers noted that it is unlikely that the team's approach can save 10% fuel economy (the SSEC goal) in any reasonable real-world cycle-averaged scenario, adding that the team noted that only 5% improvement was likely for Class-8 vehicle platforms. Another person stated that the group realizes the practical objective of perhaps a 5% fuel economy instead of 10%, which is a more realistic view at this point. This objective still aligns with the DOE petroleum displacement goal. Similarly, one person wrote that waste heat recovery in general can increase the fuel economy of vehicles; therefore this project is in line with the DOE goals. Another person commented that reduction in parasitic loads in vehicles can reduce cycle average and real-world fuel consumption. No requirement for the total amount of fuel savings is requested, and there will certainly be some savings.

One response noted that the group plans to target a large truck platform and develop a 1-kW prototype, which they hope they hope to scale-up to a 10 KW system. One other respondent, concentrating on a different aspect, commented that MSU spent their efforts in looking at new thermoelectric materials as well as design of power electronics to help integrate TE modules into vehicle waste heat recovery system.

Question 2: Are the goals of the project technically achievable? Have the technical barriers been identified and addressed? Is the project likely to overcome those technical barriers? Please comment on the project's strategy for deployment of technologies.

One reviewer stated that the multiple approaches to materials improves the likelihood that goals will be achieved, adding that the group has done a good job identifying the technical barriers associated with mechanical stresses and head transfer. However, the path to overcoming the mechanical limits of the materials is not clear. Similarly, another person stated that it is unclear if they can overcome the heat transfer and durability requirements inherent to an automotive/heavy truck application. Team acknowledges and is well aware of the challenges inherent in this technology and has made a reasonable assessment of the potential for this technology. Technology goals may be met in the longer-term, but it is unlikely that the major barriers can be addressed in the timeframe of this program.

Another person approved of how the team addressed questions from the last review: material properties; power electronics was included in the system study, which showed improvement to the power output; mechanical properties (work with ORNL); modules were made with different sizes, and tested; FEA model of the 16-leg module. The person added that the team now needs to think about packaging issues.

One reviewer commented that using CFD for heat transfer and fluid flow calculation is appropriate for designing and predicting the performance of TEG.

Overall, one response noted that: (a) A project goal of 10% increase in fuel efficiency in not likely, but significant progress can be made. The group believes that 5% is achievable. (B) The barriers have been identified. A lot of work on mechanical testing of the materials and modules is in progress. (C) The PI's have a strong team in place to address these barriers. (D) The PI's understand the overall goals of the program. There were several comments about the LAST materials not performing as originally expected. However, they did show results of LAST materials performing at about a ZT ≈ 1.2 level. It would be very beneficial to show time temperature performance curves of these materials. There was also mention of investigating new PbTe / PbS materials with an expected ZT ≈ 1.6, but they did not show any of these results or discuss them in any depth. They also made predictions of ZT values of materials that had not been synthesized. This should be avoided and ignored programmatically. This reviewer added that the addition of the large hot press is very positive, allowing the group to test "non-laboratory" samples to be able to identify what the "real world" ZT values of new materials might be in a scale-up fashion. This is very positive in evaluating the materials and eventually device performance. In a closing comment, the person noted that the group did not perform an economic feasibility study, and that the role of Cummins was not at all clear from the presentation.

In a similar format, one reviewer commented that there was (1) good strategy on materials development (on alternate material systems in addition to LASTS) and that collaboration with Northwestern team was excellent, (2) good approach to solving problems of heat transfer issues, (3) excellent plan for characterization – particularly mechanical properties (is there any plan to improve the mechanical properties of the brittle materials?), and (4) good approach to use finite element analysis. Overall, generally positive comments were offered.

Question 3: Characterize your understanding of the technical accomplishments and progress toward DOE goals: please state the reasons for your assessment.

One person stated that the project has made reasonable progress in the technical analysis and prototype development, including incorporating power electronics, mechanical stress analysis and module design, heat transfer issues, and performance calculations. The person added that the team now needs to work on packaging issues of the system. Another review states that a reassessment of the system viability is very reasonable with modified goals, noting that reevaluation of the materials, heat transfer equipment, and approaches towards eliminating minor losses in the system may yield small efficiency gains. New materials are being evaluated, but, again, the time horizon for commercializable products seems to be further off. The reviewer adds that it would be useful to compare the Cummins Rankine Recovery system to the Cummins thermoelectric recovery system in terms of fuel economy improvement, cost, weight, volume, manufacturability, payback time, and potential for further efficiency gains under the same operating conditions.

One respondent stated that the work on PbTe-PbS materials shows an alternative path to meeting the program goals. This person is still concerned about the scale-up and reproducibility of LAST materials, but adds that there is good progress toward integrating power electronics to improve power output. There was talk about enhanced heat transfer on the hot side through gas jets, but little on the cold side, which is just as crucial.

One person simply stated that MSU has a good strategy for accomplishing the task.

Another reviewer noted that the team has developed and down-selected several materials. They really need to decide on a material and proceed. Last year it was LAST, now PbTe and all have been quoted as a ZT > 1.3. Have these been validated? They decided on a vehicle platform, which is a good one, and a large engine platform may be much better at achieving the DOE goals. However, Cummins' role is unclear from the presentation. The reviewer asks: how will they get the TE generator designed without a lot of input from Cummins? They have not performed a cost analysis, and they appear to be further behind the other two teams in actually developing a prototype TE generator.

One final reviewer commented that, in general, the progress is excellent and each objective is pretty much fulfilled. This person adds that it was an excellent idea to use the finite element analysis to evaluate stress distribution in order to improve module design, and there were very encouraging results shown in their performance calculations (two TEGs can give 3-6% improvement in brake-specific fuel consumption).

Question 4: What is the likelihood that the project team will move the technologies toward or into the marketplace? Please state the reasons for your selection.

Reviewers generally had mixed reactions to this question. One individual stated that it is likely that many of the individual technologies can be migrated into the marketplace, but it is hard to assess whether there will be a viable market for them at this early stage. Another added that the team is still in the process of a lot of testing and needs to move forward with the prototype device. This person added that working out materials issues and mechanical problems seems to be taking too long.

One person stated the partnership with Cummins improves the likelihood of transition, adding there are still significant materials challenges needed to meet the goals. Similarly, another person added that, since the team works with a company to produce the module, it is only natural for the research to be commercialized if the cost-output ratio is feasible.

One response commented that the group has shown good progress towards technology transfer -- excellent improvement in module fabrication and performance, and also because they are already working with Tellurex in making preproduction prototype modules for cost estimation. Similarly, another person felt that it was a good idea to work with a TE manufacturer such as Tellurex for TE modules fabrication and final product testing.

Question 5: How sufficient are the resources for the project to achieve the stated milestones in a timely fashion?

Multiple reviewers felt that the current resources were reasonable and appropriate, and that the team seems to have covered the major aspects required to deliver the requirements of this program. One person specifically stated the team has sufficient resources available in terms of materials synthesis and characterization as well as mechanical properties modeling and characterization, but the question will actually be developing a prototype model and installing it on a Cummins engine. How will Cummins facilitate this?

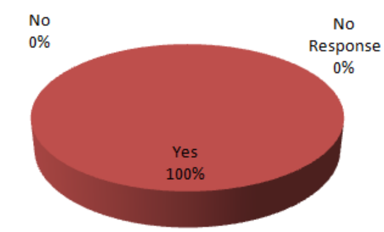
Another reviewer added that there is still significant technical work to be done, noting that the group plans to build a 1 kW generator in the next year, but only have about $400K left. One final response added that the collaborations with JPL as well as Tellurex are the most efficient way to carry out the task in a timely fashion.

Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.

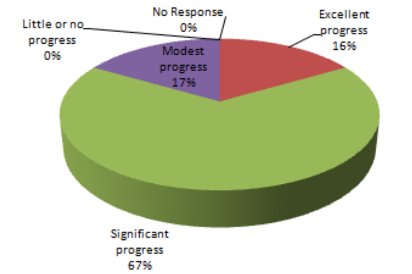
There were no expository comments for this question: refer to the graphic on the next page for this project's summary score.

Project: Thermoelectric Conversion of Waste Heat to Electricity

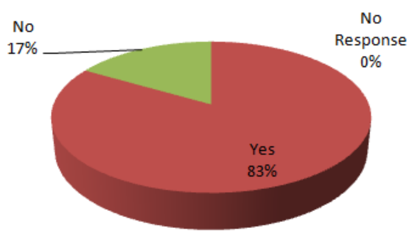
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



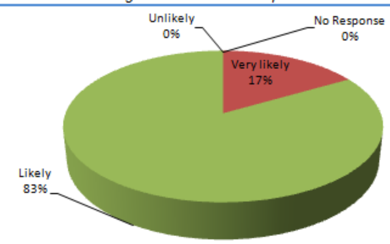
Question 3: Characterize the technical accomplishments and progress toward goals.



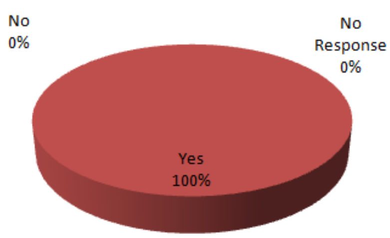
Question 2a: Are the goals of the project technically achievable?



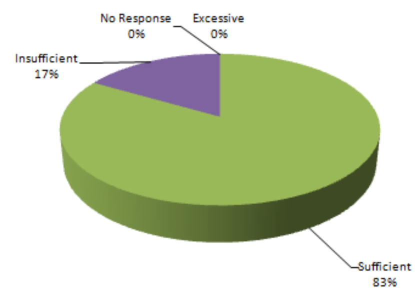
Question 4: How likely is the project team to move technologies into the marketplace?



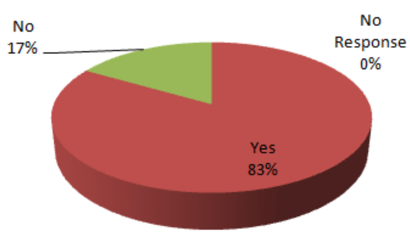
Question 2b: Have the technical barriers been identified and addressed?



Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



Question 2c: Is the proposed work likely to overcome technical barriers?



Question 6: Overall Rating