8. Propulsion Materials

The Vehicle Technologies Office (VTO) supports early-stage research and development (R&D) to generate knowledge upon which industry can develop and deploy innovative energy technologies for the efficient and secure transportation of people and goods across America. VTO focuses on research that industry either does not have the technical capability to undertake or is too far from market realization to merit sufficient industry focus and critical mass. In addition, VTO leverages the unique capabilities and world-class expertise of the national laboratory system to develop new innovations for significant energy-efficiency improvement. VTO is also uniquely positioned to address early-stage challenges due to its strategic public-private research partnerships with industry (e.g., U.S. DRIVE and 21st Century Truck Partnerships) that leverage relevant technical and market expertise, prevent duplication, ensure public funding remains focused on the most critical R&D barriers that are the proper role of government, and accelerate progress—at no cost to the Government.

The Propulsion Materials (PM) activity supports research to develop higher performance materials that can withstand increasingly extreme environments and address the future properties needs of a variety of relevant high-efficiency powertrain types, sizes, fueling concepts, and combustion modes. PM applies advanced characterization and multi-scale computational materials methods, including high-performance computing, to accelerate discovery and early-stage development of cutting-edge structural and high-performance materials for cleaner, more efficient powertrains. Research areas include Higher-Strength Materials for Elevated Temperatures; Lightweight Powertrain Alloys; and Integrated Computational Materials Engineering (ICME) Tools that combine high-performance computing capabilities, multi-length material models, and boundary-layer resolved thermos-kinetic models.

Subprogram Feedback

The U.S. Department of Energy (DOE) received feedback on the overall technical subprogram areas presented during the 2017 Annual Merit Review (AMR). Each subprogram technical session was introduced with a presentation that provided an overview of subprogram goals and recent progress, followed by a series of detailed topic area project presentations.

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

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

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

Question 3: Were important issues and challenges identified?

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

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

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

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

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

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

Question 10: Has the program area engaged appropriate partners?

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

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

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

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

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

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

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

Presentation Number: lm000 Presentation Title: Material Technologies – Overview
Principal Investigator: Felix Wu (U.S. Department of Energy)

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

Reviewer 1:
The reviewer stated that the current program area for Materials Technology was covered very thoroughly including background, overarching strategy, focus areas and program goals. The current approach to address strategic future challenges and significant opportunities is somewhat dated; however, the presentation indicated that revisions are underway. The presentation addressed materials research that is ongoing to reach VTO goals by 2030 including the types of materials and where they will be used in commercial vehicles. The presentation also described the trend for increasing fuel efficiency using weight reduction and materials research in the area of internal combustion engines (ICE).

Reviewer 2:
The reviewer said that the strategy was well-stated.

Reviewer 3:
The reviewer commented that the program area was adequately covered for ICEs. However, the scope needs to be broader to identify material challenges for electrified vehicles.

Reviewer 4:
The reviewer noted that the Materials Technology program contains two portfolios (lightweight and powertrain). The issues related to the two portfolios are presented and the outcomes from the past were discussed. The future direction of the portfolios including budget were presented. Even though the future budget is yet to be confirmed, planning for the program had been presented. Inputs were sought from participants during a separate discussion in the evening.

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

Reviewer 1:
The reviewer said that the balance between near-term and mid-term R&D is well balanced to address the challenges in materials research as defined in the VTO Multi-Year Program Plan (MYPP). The long-term R&D requirements are currently being restructured and should be based on the revision of the Materials Technology roadmap that will address any new challenges and R&D opportunities over the next 5-10 years.

Reviewer 2:
The reviewer observed that the objective is well balanced between near-, mid- and long-term activities.

Reviewer 3:
The reviewer suggested that the presenter provide a roadmap that shows the near-mid-long term research clearly with timeline.

Reviewer 4:
The reviewer stated that because the lightweighting portfolio is relevant even when complete electrification of vehicle propulsion occurs, it is necessary to look into the long-term future. While the work on aluminum (Al) alloys caters to the near- and mid-term focus, the research on magnesium (Mg) and carbon fiber-reinforced polymer (CFRP) caters to the long-term future. In case of powertrain materials, the reviewer remarked that the development of materials for high temperature stability is the only area of focus which will benefit in near- and mid-term goals. The program is not planning to work on long-term research.

Question 3: Were important issues and challenges identified?

Reviewer 1:
The reviewer stated that the issues and challenges for the current program were adequately addressed and that the major accomplishments supported how the program has addressed these issues. Future issues and challenges are currently under review in order to properly structure the program to address new issues and challenges.

Reviewer 2:
The reviewer said that the benefit and importance of this program is well stated.

Reviewer 3:
The reviewer remarked that issues and challenges were addressed to some extent. The reviewer would like to see gaps and/or challenges identified and presented for existing projects moving forward.

Reviewer 4:
The reviewer noted that the fuel efficiency improvement is the major challenge; this is the focus of the two portfolios. The powertrain materials research focuses also on emissions.

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

Reviewer 1:
The reviewer remarked that plans were identified for addressing issues and challenges. The presenter addressed the current plan to update and revise the matrix for future opportunities, critical challenges, and impacts of a variety of materials and issues that may arise for incorporating materials into vehicle lightweighting projects. The presenter also stated that a meeting of representatives from industry, academia and government was being held during the Annual Merit Review (AMR) to start changes to the matrix. These inputs will assist in updating the matrix so that it can be used for development of a revised Materials Technology roadmap to aid in funding future research projects.

Reviewer 2:
The reviewer said that the future program identifies the possible areas of research for both portfolios (lightweighting and powertrain).

Reviewer 3:
The reviewer stated that no plan was presented for addressing issues and challenges.

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

Reviewer 1:
The reviewer noted that there were five areas addressed that benchmarked progress in terms of accomplishments that has occurred over the last year. In each case, the innovations and impacts of the accomplishments were detailed.

Reviewer 2:
The reviewer stated that the major achievements in five different projects were presented highlighting the past achievements. No roadmap was presented explaining the current developments against the older ones.

Reviewer 3:
The reviewer remarked that accomplishments were presented but not in an incremental manner relative to last year.

Reviewer 4:

The reviewer was not able to connect fiscal year (FY) 2017 results to FY 2016. The presenter focused too much on the innovation aspect which is "ok" but difficult to compare the progress from last year.

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

Reviewer 1:

The reviewer said that the projects in the Materials Technology area are addressing broad problems and barriers in the VTO such as reducing the weight of an ICE vehicle by 10% to improve fuel economy by between 6% and 8%, and achieving a 13% improvement in freight efficiency from a 6% reduction in vehicle structural weight. Also, research in catalysts will help to improve combustion efficiencies for highly efficient gasoline engines. Progress is being accomplished through projects for lightweight metals, composites and multiple-material joining methods for these materials as well as new high temperature alloys and catalysts for more efficient combustion.

Reviewer 2:

The reviewer stated that both problems of fuel efficiency and emissions are addressed by the portfolios.

Reviewer 3:

The reviewer would like to see electrified vehicles to broaden the scope.

Reviewer 4:

The reviewer did not feel that the projects were addressing the broad problems and barriers. The propulsion material projects do not include lightweight driveline.

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

Reviewer 1:

The reviewer commented that the Materials Technology program is focused on addressing the need to provide lightweight material and propulsion systems solutions to the automotive industry that will achieve fuel savings in future vehicle designs. The ICME efforts demonstrated excellent collaboration between academia, the national laboratories and industry (original equipment manufacturers (OEMs) and suppliers). Considering the small budget for the number of projects, the program appears to be well managed and is very effective in achieving the goals in the current VTO MYPP.

Reviewer 2:

The reviewer agrees that the program appears to be focused, well-managed, and effective.

Reviewer 3:

The reviewer stated that the focus for both portfolios is on Integrated Computational Materials Research and computer aided decision making. The work on CFRP may be over extended with many projects during the review process.

Reviewer 4:

The reviewer remarked that the group headcount of two persons was insufficient to achieve a focused, well-managed portfolio.

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

Reviewer 1:

The reviewer noted that the key strength of projects in this program is the focusing on the correct material solutions for addressing lightweighting of vehicle structures and combustion engines. An additional strength is the highly effective collaboration between academia, national laboratories and industry that is resulting in good transition of lightweight materials technologies and ICME products to the automotive industry. The weaknesses of projects in this program are the lack of defined transitions in certain areas of propulsion materials and the slow execution of specific projects; e.g., a 2013 FOA project that has only reached 50% of its goal after 4 years of research. Projects are normally not funded for more than 5 years.

Reviewer 2:

The reviewer identified the key strength as reducing cost and weight using a multiple-prong approach. The primary weakness identified was not including electric vehicles (EVs) to reduce the weight (e.g., cables or motor).

Reviewer 3:

The reviewer identified the key strengths as the work on development of ICME tools for metals, and low-cost carbon fiber (CF). The reviewer identified the key weakness as the joining of CFRP with other metals using mechanical joining. The destruction of CF reduces the effectiveness of joining. This has been understood for a long time but still there are a few projects or tasks studying this effect.

Reviewer 4:

The reviewer noted the key strengths as an understanding that progress is made with a vertical supply chain project team. The primary weakness identified by the reviewer was that the funding awards include large consortium projects which include many universities, several DOE national laboratories, several OEMs and several suppliers. Felix even stated "the Friction Stir Welding project is a great demonstration of a well-balanced project team, which delivers results."

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

Reviewer 1:

The reviewer noted that in some cases the approach is very novel. For example, joining methods for dissimilar metals using high temperature fusing technology and tailored welds, ICME design and crash validation of structural components made of lightweight metals and composites, and next generation three-way catalysts to improve combustion efficiency at lower temperatures.

Reviewer 2:

The reviewer stated that the approach taken for the projects is quite unique and would forward to seeing future progress in the next meeting.

Reviewer 3:

The reviewer commented that some projects are quite innovative in the use of current testing and computational expertise. The examples include the hydrogen intake in Mg and ICME of steel alloy development.

Reviewer 4:

The reviewer said that these projects represent novel and/or innovated ways. The reviewer further noted that ICME and science-based projects have achieved incremental progress.

Question 10: Has the program area engaged appropriate partners?

Reviewer 1:
The reviewer remarked that, for the projects presented, there was outstanding collaboration between academia, the national laboratories, manufacturers, automotive partnerships, and first-tier suppliers. The slides that showed the organizations' logos and described the program partnerships is an excellent example of collaboration. The description of the Lightweight Materials Automotive Consortium is another good example of how to connect industry with a network of 10 national laboratories.

Reviewer 2:
The reviewer stated that the program has engaged appropriate partners.

Reviewer 3:
The reviewer said that overall, the number of partners involved in the projects is healthy. However, in some projects the partners do not contribute significantly to technical expertise of other resources. The partners seem to get involved only for in-kind cost contribution.

Reviewer 4:
The reviewer said that the program has engaged appropriate partners, just too many on the same project.

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

Reviewer 1:
The reviewer stated that, based on the technology transitions described, the program appears to be collaborating very effectively in the majority of the projects. This appears to be occurring with hardware as well as software developers and suppliers.

Reviewer 2:
The reviewer considered it difficult to comment due to limited information.

Reviewer 3:
The reviewer did not feel the program collaborated with partners effectively. The lack of staff (two total) does not enable sufficient time to collaborate.

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

Reviewer 1:
The reviewer noted that the only possible gap would be the current lack of definition and prioritization of research efforts in the Materials Technology Program for the next five to 10 years. With the potential for reduced budgets, it is important that the proper areas of research be defined to allow funding to be applied in those areas. Hopefully this will be resolved with the revision to the significant opportunities and critical challenges matrix.

Reviewer 2:
The reviewer would prefer to see the scope extended beyond ICEs.

Reviewer 3:
The reviewer said that a major review of the current state-of-the-art may be needed. The last review was done a few years ago.

Reviewer 4:
The reviewer identified driveline and technology projects to overcome commercialization barriers as the key gaps.

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

Reviewer 1:

The reviewer noted that the overview presentation did not allow time for a description of the full Materials Technology portfolio. In general, all areas of materials research (metals, CF and composites, methods of multiple-material joining, integrated computational materials engineering, high temperature materials, and materials to improve propulsion systems) adequately address the needs to meet VTO goals.

Reviewer 2:

The reviewer identified life cycle analysis (LCA) as a topic not adequately addressed. Cradle to grave analysis needs to be part of every project. This methodology identifies CO_2 associated with production, use and recycling. Every recipient must be forced not to ignore LCA.

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

Reviewer 1:

The reviewer noted that the program is described as addressing problems with well-known materials (Al, Mg, high-strength steels, and CFs) where automotive manufacturers and first-tier suppliers have the most interest. Future materials will use nanotechnology to provide better properties and characteristics that will be applicable to the automotive industry. The reviewer suggested that some investment should be made in those areas to further meet or exceed VTO programmatic goals.

Reviewer 2:

The reviewer recommends considering EVs.

Reviewer 3:

The reviewer noted that the research on propulsion materials to reduce emissions will be useful.

Reviewer 4:

The reviewer identified the area of lightweighting relative to driveline and transmission systems. Demonstrating efficiency related to mass reduction versus general engine downsizing should be considered, which results in 6% for every 10%.

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

Reviewer 1:

The reviewer stated that the current approach is very good for addressing near-term and mid-term barriers and challenges. New challenges will prevail for the long-term over the next decade and the program should be prepared to address them. Research organizations that are developing cutting-edge technologies should be solicited for input as to what will be the future generation of materials and how they may apply to VTO future goals. Until there is an update to the VTO MYPP, this may be a difficult task.

Reviewer 2:

The reviewer commented that the course being taken by the current team is good; international collaboration and funding to support could improve the pace of research.

Reviewer 3:

The reviewer would like to see a broader view of the material technologies in terms of the roadmap along with describing the challenges associated with each area. The reviewer said that less focus should be placed on describing innovations.

Reviewer 4:

The reviewer recommended LCA as a new way to approach the barriers, using metrics such as total manufactured cost at volume of 100,000 or 250,000 units per year.

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

Reviewer 1:

The reviewer remarked that, overall, the Materials Technology program is very effective. A few of the projects have poor execution and should be re-directed to better meet the goals and milestones of the research. Some projects do not have transition partners identified in the early stages of the projects and the principal investigators should be encouraged to identify partners in the first year of their projects.

Reviewer 2:

The reviewer recommended increasing the size of the group in order to better manage and engage with projects instead of simply monitoring them. This reviewer strongly advised that the program MUST stop funding several programs that have not met go/no-go objectives.

Project Feedback

In this merit review activity, each reviewer was asked to respond to a series of questions, involving multiple-choice responses, expository responses where text comments were requested, and numeric score responses (*on a scale of 1.0 to 4.0)*. In the pages that follow, the reviewer responses to each question for each project will be summarized: the multiple choice and numeric score questions will be presented in graph form for each project, and the expository text responses will be summarized in paragraph form for each question. A table presenting the average numeric score for each question for each project is presented below.

Table 8-1 – Project Feedback

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
pm053	High-Temperature Engine Materials: Valve Materials Subtask	G. Muralidharan (ORNL)	8-12	3.50	3.60	3.50	3.50	**3.55**
pm057	Applied Computational Methods for New Propulsion Materials: Future Engine Requirements	Charles Finney (ORNL)	8-16	3.40	3.30	3.10	3.40	**3.31**
pm060	ICME Guided Development of Advanced Cast Aluminum Alloys for Automotive Engine Applications	Mei Li (Ford Motor Co.)	8-21	3.50	3.38	3.00	3.25	**3.34**
pm061	Computational Design and Development of a New, Lightweight Cast Alloy for Advanced Cylinder Heads in High-Efficiency, Light-Duty Engines	Mike Walker (General Motors)	8-25	3.30	3.20	3.40	3.10	**3.24**
pm062	High-Performance Cast Aluminum Alloys for Next-Generation Passenger Vehicle Engines	Amit Shyam (ORNL)	8-29	3.80	3.80	3.70	3.60	**3.76**
pm066	Innovative SCR Materials and Systems for Low-Temperature Aftertreatment	Yong Wang (PNNL)	8-34	3.25	3.19	3.13	3.19	**3.20**
pm067	Next-Generation Three-Way Catalysts for Future, Highly Efficient Gasoline Engines	Christine Lambert (Ford Motor Co.)	8-39	3.17	2.83	3.17	3.00	**2.98**

Presentation ID	Presentation Title	Principal Investigator (Organization)	Page Number	Approach	Technical Accomplishments	Collaborations	Future Research	Weighted Average
pm068	Sustained Low-Temperature NO_x Reduction (SLTNR)	Yuhui Zha (Cummins)	8-42	3.14	3.36	3.36	3.29	**3.29**
Overall Average				**3.37**	**3.35**	**3.30**	**3.30**	**3.34**

Presentation Number: pm053
Presentation Title: High-Temperature Engine Materials: Valve Materials Subtask
Principal Investigator: G. Muralidharan (Oak Ridge National Laboratory)

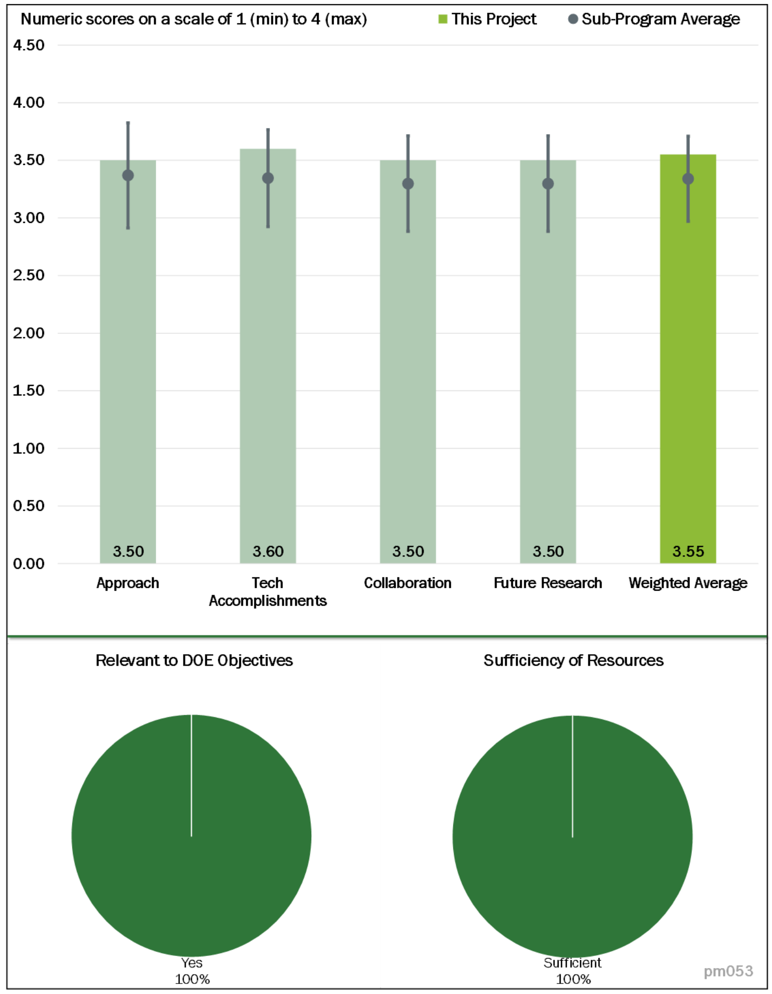

Figure 8-1 - Presentation Number: pm053 Presentation Title: High-Temperature Engine Materials: Valve Materials Subtask Principal Investigator: G. Muralidharan (Oak Ridge National Laboratory)

Presenter
G. Muralidharan, Oak Ridge National Laboratory

Reviewer Sample Size
A total of five reviewers evaluated this project.

Question 1: Approach to performing the work—the degree to which technical barriers are addressed, the project is well-designed,

Reviewer 1:
The reviewer stated that the project looks well designed and has identified both the technical and cost barriers associated with the chromia- and alumina-based valve materials for high-temperature applications.

Reviewer 2:
Though not a materials scientist, the reviewer declared that the approach for the project was good and that the presenter did a good job explaining the motivation for the approach of the project.

Reviewer 3:
The reviewer remarked that the principal investigator (PI) addressed the comments from previous reviews to focus this new project effort on finding new alumina-forming alloys for exhaust valves. The reviewer noted that oxidation resistance was an issue at high temperatures so, to address this issue, an increased percentage of alumina was added to the alloy to offset oxidation; however, doing this lowers the strength of the material. The reviewer commented that the project team used a computationally guided approach to investigating alloys that balanced strength, oxidation resistance, and cost, which are needed to achieve the end targets. The reviewer stated that cost constraints and targets must be met for success and that mechanical property improvements may be obtained via heat treatment and possibly other techniques.

Reviewer 4:
The reviewer believed that the team's approach appeared to be focused upon overcoming specific barriers associated with increasing exhaust gas temperatures. The reviewer commented that the baseline material does not appear to have significant strength above 850° Celsius (°C), which will be required in the future. The reviewer identified one concern in the approach, which was that the project is focused overall upon providing increased performance materials while remaining cost-effective; however, there did not appear to be any

specific cost targets identified for the project. The reviewer noted that several proposed alloys appear to have comparable or slightly better costs than the baseline. The reviewer stated that the project should identify if comparable cost is the target, or if there is a price premium that might be considered acceptable to ultimate users.

Reviewer 5:

The reviewer commented that the basic premise for the project was that newer engine technologies will require higher exhaust temperatures and that currently available, relatively affordable alloys were limited in strength to 870°C. Newer alloys with sufficient strength at higher temperatures, up to 950°C, are required.

The reviewer agreed that newer engine combustion concepts mandate operation at higher in-cylinder pressures, but stated that the requirement of operational capabilities of the valves at higher temperatures was new information. The reviewer proposed that the presenter should share the supporting background information for this newer specification (i.e., what source provided this requirement).

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

Reviewer 1:

The reviewer commented that the activities appear to be progressing in accordance with the plan. The reviewer noted that some alloys meet or exceed certain performance criteria (such as strength), while others meet other criteria (such as oxidation resistance). Thus, the reviewer remarked that the project was looking at how to balance the compositions versus performance criteria. It was apparent to the reviewer that the project team was getting closer to achieving this balance by demonstrating revised alloys that appear to show significantly better performance, but “yield strength” improvements, without losing oxidation resistance, were still required.

The reviewer also stated that project has identified some gaps in availability of needed predictive models.

Reviewer 2:

The reviewer surmised that because existing alloys cannot meet the requirements at 950°C, the project team had identified cost, high-temperature strength, and oxidation resistance to be the three critical parameters. The reviewer believed that through trials of optimizing these three characteristics, the project team opted for alumina scale-forming alloys instead of the current chromia scale-forming ones. The reviewer commented that the project team managed to develop two alloys that meet the requirements.

Reviewer 3:

The reviewer affirmed that for the amount of funding allocated for this effort, significant progress has been accomplished. The reviewer concluded that was due in part to leveraging previous research to focus the effort of this project on a targeted alloy. The reviewer noted that the material downselect was successful and that further improvements to mechanical properties would be achievable through heat treatment and other processes.

Reviewer 4:

The reviewer noted that the project team was well able to differentiate the two alloying materials and create new material compounds with lower cost that achieve most targets.

Reviewer 5:

The reviewer stated that the project team’s technical accomplishments were very good.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that the team was working well with collaborators, obtaining valve materials for comparisons, and carrying out tests, such as the work done with Gleeble.

Reviewer 2:
The reviewer stated that the project had excellent team partners, who possess the requisite expertise and access to relevant developmental facilities.

Reviewer 3:
The reviewer said that the collaboration was good and the collaboration partners were appropriate.

Reviewer 4:
The reviewer noted that the project partners include two materials suppliers and Argonne National Laboratory, and that the partners were appropriate given the stage of the project. The reviewer commented that later efforts might require working with component or engine manufacturers to allow for evaluation of the material in an actual valve application.

Reviewer 5:
The reviewer believed that the national laboratory and industry collaboration was excellent; however, the addition of academia would improve collaboration even further.

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

Reviewer 1:
The reviewer found the project team to be properly focused on the alumina formers while trying to increase temperature and strength. The reviewer commented that the project team has identified limitations of both alloys and is designing new alloys and processes to find an optimum, which does appear to be the most logical direction for the project.

Reviewer 2:
The reviewer stated that the remaining efforts appear targeted at achieving project goals and, given progress to date, the reviewer believed that the project would succeed.

Reviewer 3:
The reviewer commented that the projected future research was a natural extension of the work performed so far.

Reviewer 4:
This reviewer believed that the future work appeared to be a reasonable extension of the current status.

Reviewer 5:
The reviewer noted that the focus of future work should include mechanical property improvements prior to investigating alternative alloy configurations, which would maintain focus on achievement with a realistic timeline. The reviewer stated that the mechanical property improvements appeared to be obtainable via microstructure improvement techniques, like heat treatment. Finally, the reviewer suggested that this be the initial focus of the future research prior to investigating alternative alloy configurations and that the project team needed to continue to look for opportunities to leverage previous work into this project.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that engine efficiency can be increased by increasing temperature and pressures in the combustion chamber, but this requires materials capable of operating at higher temperatures without significantly added cost. The reviewer believed that this project aims to increase the temperature capabilities of valve materials without significant cost additions, which is in alignment with DOE goals.

Reviewer 2:
The reviewer commented that the project effort was focused on improved engine valve materials to allow for higher efficiency operation. The reviewer believed that the expectation in the industry is that exhaust gas temperatures will continue to rise, requiring higher performance materials; therefore, this project is relevant work.

Reviewer 3:
The reviewer observed that the high-temperature alloys developed in this effort would enable newer combustion concepts that, in turn, lead to reduced petroleum consumption. As a result, the current project aligns with DOE goals.

Reviewer 4:
The reviewer stated that materials that maintain their strength at higher engine temperatures will facilitate improved engine performance; therefore, this is very relevant work.

Reviewer 5:
The reviewed noted that high operational temperatures enable higher efficiency engine operation, which aligns with DOE goals.

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

Reviewer 1:
The reviewer stated that the researchers are making good progress and have defined the appropriate list of tasks for the budget they have.

Reviewer 2:
The reviewed observed that the resources are commensurate with the projected effort.

Reviewer 3:
The reviewer believed that the funding appeared sufficient for this project.

Reviewer 4:
The reviewer did not identify any funding concerns.

Presentation Number: pm057
Presentation Title: Applied Computational Methods for New Propulsion Materials: Future Engine Requirements
Principal Investigator: Charles Finney (Oak Ridge National Laboratory)

Presenter

Charles Finney, Oak Ridge National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

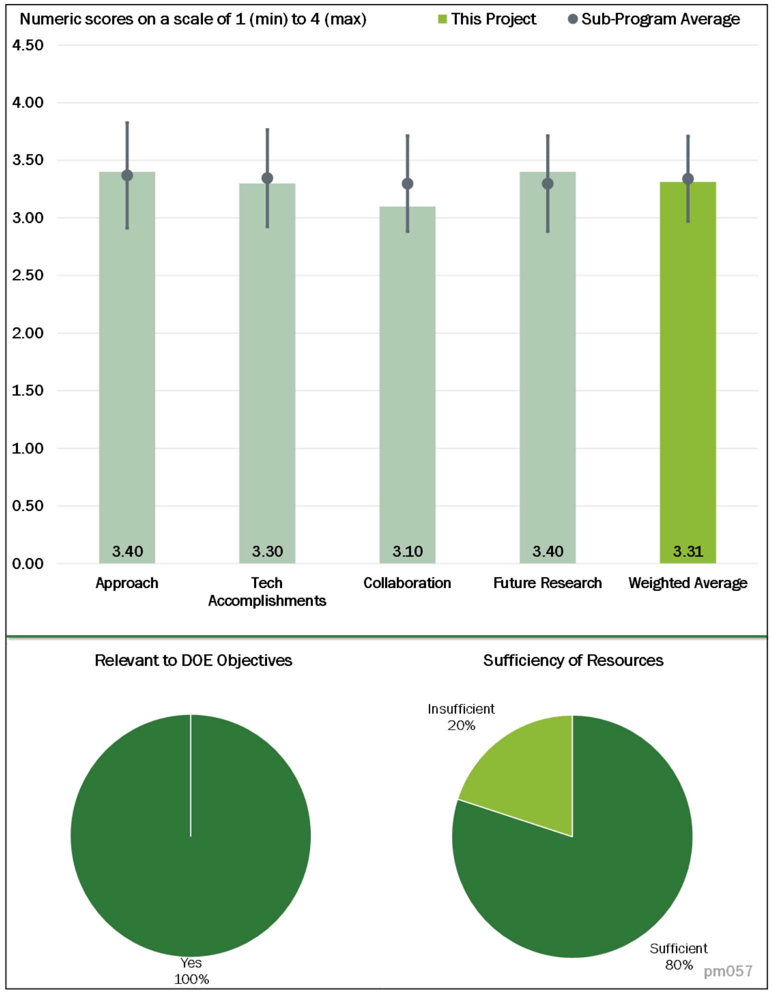

Figure 8-2 - Presentation Number: pm057 Presentation Title: Applied Computational Methods for New Propulsion Materials: Future Engine Requirements Principal Investigator: Charles Finney (Oak Ridge National Laboratory)

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

Reviewer 1:

The reviewer stated that approach is starting to show very solid signs of bringing computational fluid dynamics (CFD) and finite element modeling (FEM) together effectively, which was a good reflection on the overall program plan. The reviewer highlighted that the pressure was on to close the project out over the next year or so and really take the complexity to the next level. This step was important in order to prove that all critical factors are being included. The reviewer expressed that the mono-material model of the head, for example, would be extraordinarily beneficial as componentry is added with varying properties.

Reviewer 2:

The reviewer observed that the project was using applied computational methods to investigate solutions to engine material requirements for high-efficiency heavy-duty (HD) engines, and investigating possible material configurations to solve material property degradation (yield strength, fatigue life, creep, and corrosion) caused by the higher temperatures needed for increased efficiency engines. The reviewer commented that this effort directly targets material barriers identified in the VTO Multi-Year Project Plan (MYPP).

The reviewer recognized that through the project efforts, a conjugate heat transfer model was developed and is being refined as well as an FEM for the 15-liter (L) engine to evaluate pressure and thermal effects on engine cylinder components: head, valves, and liner. Also, fatigue has been modeled to achieve materials properties targets.

The reviewer affirmed that the approach used expanded the model beyond cylinder-cylinder head-intake to all areas surrounding the cylinder to get heat transfer effects from other parts of the engine and that material characterization was well underway. The reviewer stated that the project was making good use of computer capabilities in the laboratory to run models and explore multiple combustion strategies. The reviewer concluded that the modeling was being used to identify materials development (guiding the gap analysis) to help with selecting materials of the future that could be used to meet the targeted properties.

Reviewer 3:

The reviewer noted that this work was developing a computational tool and powerful analysis techniques that could be very helpful for developing or choosing materials for extreme in-cylinder conditions. The reviewer concluded that if this work was successful, it would allow combustion systems to be developed that are not currently feasible.

Reviewer 4:

The reviewer observed that the modeling activity of this project appears to combine CFD and FEM into a predictive model for determining the in-cylinder temperature and pressure effects on component integrity. The reviewer commented that there was good coupling with engine efficiency targets, which require higher temperature materials to reach the efficiency levels that would be needed going forward. The reviewer stated that obtaining an understanding of where high-temperature events are impacting the cylinder components and how the material reacts was very important to the survivability of both HD and light-duty (LD), highly efficient engines that can work at higher temperature and pressure regimes. Therefore, the reviewer opined that this work was very appropriate for accelerated advanced material development. However, the reviewer expressed some concern that predicting these effects only using “un-aged” samples may not capture important elements of the failure mechanism related to chemical exposure.

Reviewer 5:

The reviewer remarked that the current project was attempting to tie together three different computational efforts, namely conjugate heat transfer CFD, FEM, and fatigue modeling to determine the material requirements of future high-efficiency engines. While this goal is laudable, the reviewer was concerned that given the uncertainties in computational methods and the fact that the high-efficiency combustion schemes are still evolving, the effort is open-ended. Instead, the reviewer recommended that the team collaborate with a specific OEM and concentrate on one specific high-efficiency combustion scheme that is limited by material properties.

The reviewer did not agree with some of the basic assumptions of this effort, such as the projected future peak cylinder pressures would be 300 bar (the actual pressures could be much lower to attain nitrogen oxide (NO_x) targets); some of the stress points cannot be overcome through design modifications and existing castable alloys are inadequate.

The reviewer highly recommended close partnership with OEMs and use of the knowledge base established through cut-and-try methods, rather than purely relying on computational efforts. The reviewer had an additional concern that this project was trying to establish a capability that already exists with industries, such as Nemak.

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

Reviewer 1:

The reviewer noted that the base level work appeared well-grounded and focused. The reviewer highlighted that the use of both the CFD and FEM computational elements, to better assess and predict “hot spots” and fatigue risk in cylinder component material, was worth support from a manufacturing and engineering standpoint. The reviewer stated that the predicted results appear to be fundamentally sound and consistent from experimental results and, as this was an evolving tool, the continued validation of the model with appropriate testing was needed to increase the accuracy and confidence in the results. The reviewer remarked that this work was already driving material improvements and alternatives at the manufacturing level. Also, the reviewer concluded that the project had good coupling with engine efficiency targets that require higher temperature materials to reach the efficiency levels needed going forward.

Reviewer 2:

The reviewer noted very good progress in developing the analysis techniques.

Reviewer 3:

The reviewer acknowledged some performance issues identified with selected material compacted graphite iron 450 (CGI450); however, the model was developed, which identified this issue during the testing. The reviewer commented that this failure may not be within the operational range expected in future engines as understanding these limitations present an opportunity to integrate thermal barrier materials into future engine designs.

Reviewer 4:

The reviewer noted that the progress against DOE goals as a general assessment was excellent, but the practical progress of the effort thus far is lagging a bit, which was identified by the presenter. The reviewer noted concern in that the critical components of the program are naturally toward the end and because the mechanical verification testing has been completed, the modeling and simulation portion has to start closing all of the loops. The reviewer was unsure whether there was a plan to keep things on track.

Reviewer 5:

The reviewer stated that fairly good progress had been made in characterizing high-temperature material properties and in performing conjugate heat transfer CFD modeling followed by CFD modeling to predict the high-stress regions in one-cylinder geometry. However, the reviewer noted that the issue remains that though the feasibility of this computational method has shown progress, the target for the project was determined by the researcher without the appropriate input from collaboration partners and industry.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer highlighted that because this project was focused on the development of analysis techniques and a predictive program or model, the need for collaboration with outside entities was not extensive; therefore, the current collaboration effort seems good.

Reviewer 2:

The reviewer stated that because the OEMs providing engine support were unnamed, it was difficult to state whether those collaborators fit within the team structure effectively. The reviewer highlighted that the Oak Ridge National Laboratory (ORNL) team seemed to need little in the way of outside support; nonetheless, collaboration is critical to ensure that target parameters remain accurate. The reviewer also noted that the figures presented as “current” on the graph of Slide 6 seem a bit dated.

Reviewer 3:

The reviewer stated that the presentation mentioned that the team comprised two OEMs partners, but their identity was being withheld. The reviewer recommended that a consortium of LD and HD engine manufacturers be formed to guide this effort.

Reviewer 4:

The reviewer remarked that collaboration and coordination with HD engine manufacturers was expected and employed for this work. However, the reviewer noted that incorporating LD engine manufacturers, such as passenger car OEMs, would benefit from the usefulness of this approach and gather additional support for this project.

Reviewer 5:

The reviewer stated that the presentation called out collaboration with two unnamed OEMs though there was no apparent coordination with a material producer or university.

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

Reviewer 1:

An advanced modeling approach such as this approach needs little in the way of voiced support because the ability to effectively model systems in the way that is being worked out in this program will enable continued refinement and levels of complexity, further adding accuracy to future models.

Reviewer 2:

The reviewer proposed that the project leads engage LD counterparts in this project as the HD side was already well addressed.

Reviewer 3:

The reviewer stated that the project team had very good plans for the future work and suggested that the analysis of thermal barrier coating and thermal swing treatments of the in-cylinder surfaces be integrated into future project work.

Reviewer 4:

The reviewer noted that the proposed future research was a natural extension of the work performed so far. The reviewer mentioned that the plan includes further material property determination at high temperatures, and computational modeling for fatigue.

Reviewer 5:

The reviewer stated that the CFD model looks well developed and that the next steps in the program could include the definition of required performance to meet future operating conditions. The reviewer acknowledged that the existing graphite iron options are not sufficient to meet future operational parameters; therefore, by clearly defining targets (including temperature and cost), a future material might be identified using integrated computational materials engineering (ICME) and developed for this application. The reviewer offered that because practical engines need a cast-iron material, the ICME approach may not yield an appropriate material.

The reviewer surmised that thermal barrier materials should be investigated to help with thermal management. Multiple materials (current and future candidate materials) could be folded into the advanced simulation model. Modeling could be used to identify materials development (guiding gap analysis), which would help with the selection of materials in the future that could meet the all targeted properties.

The reviewer noted that another possible future research topic would be the effect of chemical invasion into the material as these effects are not well known.

The reviewer observed that the PI proposed moving this analysis into the LD vehicle realm and scanning to develop the engine model and the use of different operating conditions. The reviewer commented that the PI should investigate getting these types of data from an OEM and should look to leverage existing resources and data when available.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer believed that the project absolutely met the objectives of reducing petroleum consumption per unit of work extracted and that the program was based on assessing the ability of emerging designs to meet increased efficiency demands.

Reviewer 2:
The reviewer commented that improved component durability—under the more-demanding temperature and pressure conditions that are present in advanced, highly efficient engines—was of high importance to manufacturers who are required to meet longer lifetimes of vehicle subsystems.

Reviewer 3:
The reviewer believed that the results of this project would allow the development of higher efficiency ICE materials.

Reviewer 4:
The reviewer was unsure whether any enablers would result from this effort although the reviewer acknowledged that this exercise was likely to develop a computational methodology to evaluate some candidate materials for advanced engine concepts.

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

Reviewer 1:
The reviewer noted that despite seemingly minor delays, the program seemed to be on a good progression schedule.

Reviewer 2:
The reviewer believed that this project was appropriately funded and staffed.

Reviewer 3:
The reviewed remarked that the researchers seem to have defined a program that would produce useful outcomes and stay within the current budget.

Reviewer 4:
The reviewer commented that the project resources appear sufficient (including carryover funds) to accomplish the goals of this project.

Reviewer 5:
This reviewer stated that at least one full-time equivalent of funding was recommended for one more year.

Presentation Number: pm060
Presentation Title: ICME Guided Development of Advanced Cast Aluminum Alloys for Automotive Engine Applications
Principal Investigator: Mei Li (Ford Motor Co.)

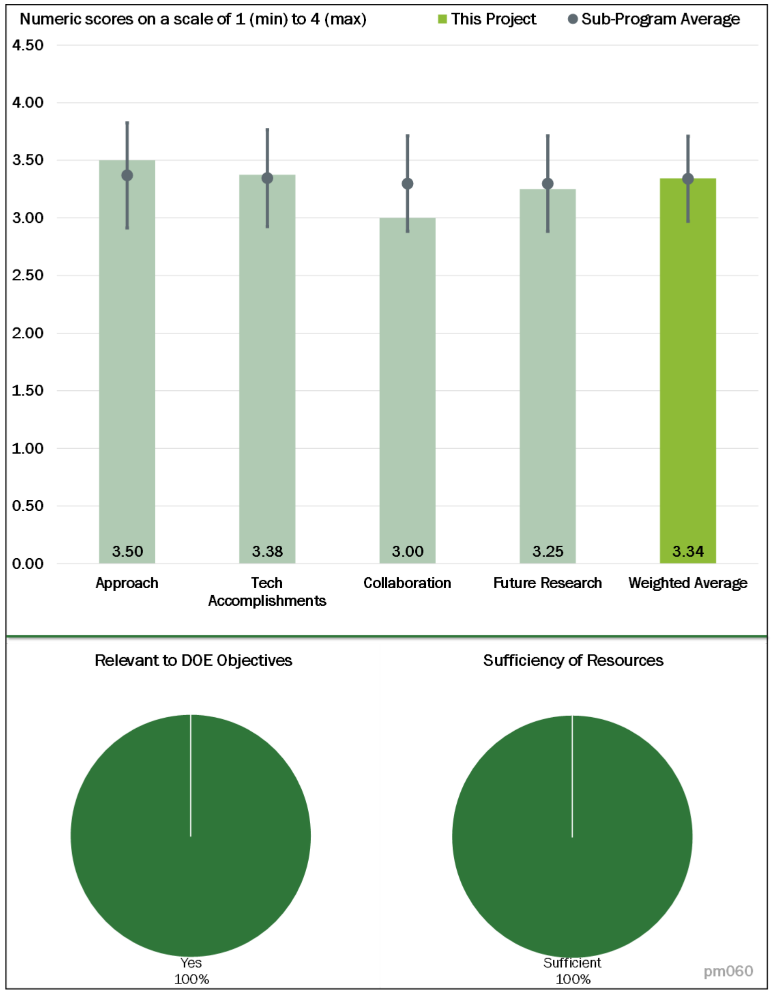

Figure 8-3 - Presentation Number: pm060 Presentation Title: ICME Guided Development of Advanced Cast Aluminum Alloys for Automotive Engine Applications Principal Investigator: Mei Li (Ford Motor Co.)

Presenter
Mei Li, Ford Motor Co.

Reviewer Sample Size
A total of four reviewers evaluated this project.

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

Reviewer 1:
The reviewer noted that the program was very focused and well thought out and acknowledged that of the technical targets for new alloy development provided by DOE, the prime technical targets—tensile strength, yield strength, and fatigue strength at high temperatures (300°C)—were identified early on in the program. The reviewer noted that through the initial efforts of this project, two new alloys and the associated thermal processing methods had been developed.

Reviewer 2:
The reviewer believed that the project was an excellent integration of simulation, alloying experiments, and characterization focused on key path of precipitates.

Reviewer 3:
The reviewer acknowledged that the Ford approach was well organized, thoughtful regarding the proposed limits (110% cost), and generally effective and commended the project team. Despite the rather extraordinary credentials of the PI and the team, however, the reviewer stated that the real ICME element was not clearly identified. The reviewer believed that TC Prisma and Pandat were making excellent progress regarding accuracy, but that the project still had a long way to go in terms of reliable predictive capabilities.

The reviewer stated that it was difficult to imagine that the layout and execution of the experimental portion, which proved largely effective, was really overly strengthened by any ties with ICME, and that the reviewer was more convinced that a good experimental matrix approach was effective in selecting compositions and heat treatments of interest based on quality observations via use of transmission electron microscopy and dedicated composition analyses. The reviewer noted that this was not a drawback necessarily but left the proposed gap analysis somewhat underpopulated.

Reviewer 4:
The reviewer remarked that the team had limited background with this material and that their own comments would not be technically based. On the other hand, the team understood that materials were critical to pushing the limits of engine performance and represent a critical component in the cost of the engine.

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

Reviewer 1:
The reviewer stated that the technical accomplishments were excellent. The project was following a well guided program plan where two alloys, whose properties met or exceeded DOE targets, had been identified. Subsequently, the reviewer asserted that during the project hardware effort, castings of a few cylinder components had been created and their mechanical properties were being tested. In parallel to the above effort, this reviewer noted that ICME methodology was followed to the extent possible to develop a model for rapid development of newer alloys and that gaps in the knowledge base were identified.

Reviewer 2:
The reviewer noted that project goals were being achieved with two materials, that the exploration of small angle X-ray to accelerate characterization appeared to be a nice innovation, and that it would be interesting to see final assessment.

Reviewer 3:
Though not a materials scientist, the reviewer noted that it was apparent that the research team was making good progress. The reviewer remarked that this program was not new this year yet the presenter did not show the standard slide addressing the previous year's reviewers' comments. The reviewer commented that having the prior year's comments would have been helpful in addressing this year's technical accomplishments. The reviewer surmised that the statements of the presenter and the comments from the audience indicated that this work will be useful and could be integrated into future production vehicles.

Reviewer 4:
The reviewer noted that the overall progress was clear from the results of mechanical testing against the experimental matrix; however, the reviewer was concerned with the project's inability to meet the proposed property improvements when the materials were exposed to the somewhat standard aging treatment (conditioning) prior to testing. The reviewer surmised that while it would appear that cylinder heads using the idealized alloy and heat treatment would be largely improved at engine assembly and bolt-up, if the material stability was lacking and the properties were lost after a reasonable amount of operation, then it was difficult to embrace the concept that real improvements have been made. The reviewer stated that these types of programs should discuss whether such post-aging (operation-based) needs to be part of the target property protocol and, if not, why that is an overly conservative treatment that is not reflective of engine operations.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that the project team was composed of members who are highly regarded and have a history together. It was clear that this team would provide the core of a number of successful future projects in addition to this one.

Reviewer 2:
The reviewer acknowledged that Ford has partnered with Nemak, which is a leading provider of aluminum castings, and Alcoa, the world's largest provider of aluminum. Overall, the reviewer commented, that the team appears to have the right expertise and access to the required manufacturing and analytical facilities. The

reviewer remarked that the University of Michigan was also listed as a partner; however, their participation in the present effort was not very clear.

Reviewer 3:
The reviewer commented that the project team collaboration was reasonable though the presenter did not comment on the role being played by the collaborators who were presently engaged with the project.

Reviewer 4:
The reviewer stated that in an otherwise outstanding presentation, the roles and achievements of the various team members were not called out either in 2016 or 2017. Because collaboration is a scored criteria, the reviewer recommended that the presenter devote a slide to contributions from team members during future presentations.

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

Reviewer 1:
Based on the material presented and current results, the reviewer stated that future plans seem good.

Reviewer 2:
This reviewer looked forward to the engine testing results, which will absolutely resolve any lingering doubt as to whether practical improvements have been made. The offer of further gap analyses is also of value. This reviewer suggested that the team should move past the use of these terms as a necessary offer when discussing ICME and embrace the fact that ICME approaches still lack considerable effectiveness in a number of areas. The reviewer strongly said to be critical here; it will help the overall ICME effort.

Reviewer 3:
The reviewer pointed out that the project is nearly complete and appropriately ends with completion of component level evaluation. The rig tests in progress are fine. The reviewer asked if there will there be engine tests.

Reviewer 4:
The reviewer noted that the two stated objectives—to develop comprehensive cost models to ensure that components manufactured with these new alloys do not exceed 110% of the cost using incumbent alloys A319 or A356, and to develop a technology transfer and commercialization plan for deployment of these new alloys in automotive engine applications—appear to have been forgotten.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer remarked that the ability to extend efficiency and performance of combustion engines through materials research that is readily deployable is absolutely within the goals of the DOE.

Reviewer 2:
The reviewer asserted that comments by the presenter indicated that the results of this work will be seen in vehicles on the road. That is great.

Reviewer 3:
The reviewer's response was a "maybe." The advanced alloys developed in this effort can potentially enable various advanced combustion schemes, which in turn may lead to reduced petroleum consumption in the United States.

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

Reviewer 1:
The reviewer observed that the team has made great progress and appears to be on track to wrap the project up successfully.

Reviewer 2:
The reviewer stated that the project is near completion, with success.

Reviewer 3:
The reviewer said that the allocated funds are commensurate with the stated scope of work.

Presentation Number: pm061
Presentation Title: Computational Design and Development of a New, Lightweight Cast Alloy for Advanced Cylinder Heads in High-Efficiency, Light-Duty Engines
Principal Investigator: Mike Walker (General Motors)

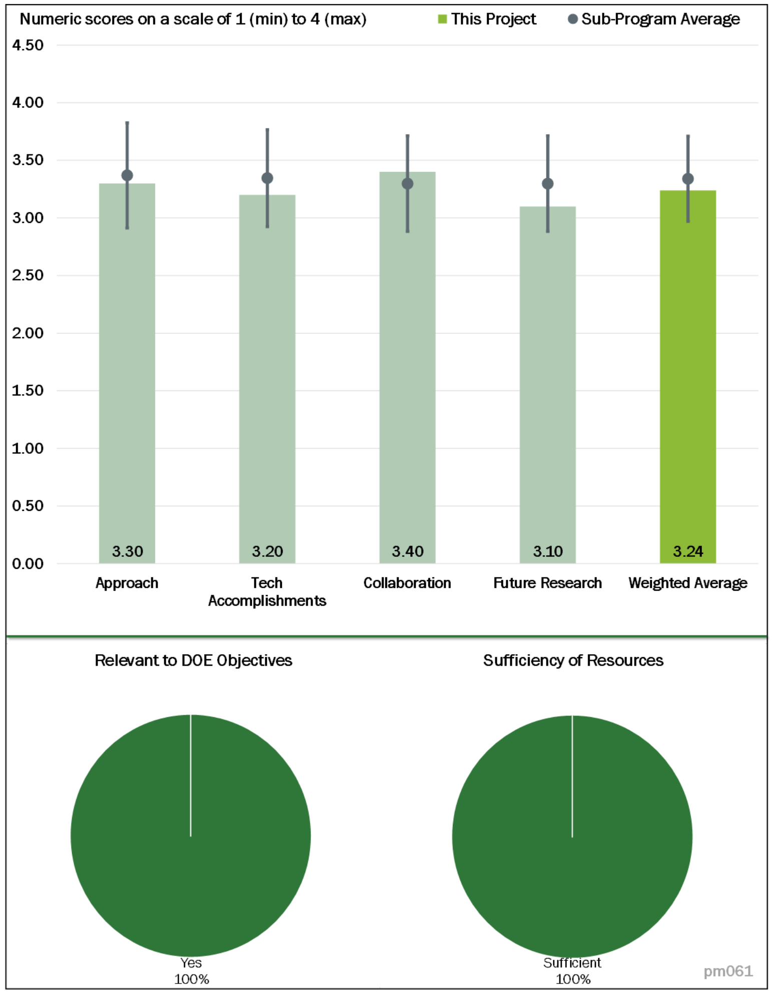

Figure 8-4 - Presentation Number: pm061 Presentation Title: Computational Design and Development of a New, Lightweight Cast Alloy for Advanced Cylinder Heads in High-Efficiency, Light-Duty Engines Principal Investigator: Mike Walker (General Motors)

Presenter

Mike Walker, General Motors

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer observed that the focus on the Q-phase has paid off and little is left to get to the casting stage. This comprehensive approach has all the classic material development steps: compositional evaluation, microstructure, modeling, mechanical testing, and castability, with a cast head end point to wrap it all up. Further work will be needed to tweak the room-temperature (RT) elongation work, but this is built into the approach.

Reviewer 2:

The reviewer stated that the researcher addresses the technical barriers of casting lightweight alloys and did good research overcoming those barriers.

Reviewer 3:

The reviewer commented that the approach looks to be sound and on a pathway to success.

Reviewer 4:

According to the reviewer, the project is showing good progress; the team and presentation of results reflect a commendable level of expertise. The ICME component seems to be largely underutilized, however. If Q-phase structure is the key to dialing up the stability and performance, the reviewer inquired about what other elemental additions outside of the normal list might stabilize it further. This reviewer further questioned whether Q based on known chemistry is really being embraced, and if it is hoped that minor changes to the DOE target properties will put the alloy over the top. The reviewer opined that, perhaps, the cost constraint is too much of a factor at this phase of the program, resulting in gentle nudges to the alloy rather than wholesale changes. The reviewer also saw a larger role for ICME in evaluating more widespread changes that can then be dialed back through experimental analyses. Overall, the program is doing extremely good work and making progress toward the goal, but the reviewer would love to have seen some attempts at bold changes being evaluated (or at least being presented as having been considered) as a component of the program.

Reviewer 5:

Perhaps in hindsight, the reviewer remarked, the project may have lacked the computational breadth and "horsepower" to explore the necessary range of alloying options. Actual engine operation and tests do not appear to be part of the project completion. At least it is not conspicuous in the schedule and task list.

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

Reviewer 1:

The reviewer said the researcher accomplished all of his goals to date.

Reviewer 2:

The reviewer found there to be good progress on the strength model development. Alloy 2 properties are approaching the DOE targets.

Reviewer 3:

The reviewer acknowledged that some technical accomplishments will add to the literature base—sub-lattice compositional work, stability range update, and strength modeling—and the reviewer liked to see this in government funded programs. All but two goals have been achieved: RT elongation and ultimate tensile strength (300°C). The goals were not easy, and the team is well on the way to achieving them.

Reviewer 4:

The reviewer expressed concern about the overall effect of the conditioning treatment and questioned whether this is a genuine representation of an engine with some operating time or an overly conservative view.

The properties following the conditioning treatment still seem to be a stumbling block, despite the fact that this drawback has apparently been identified previously and formally addressed by the team. The reviewer appreciated that the program is not complete and there are still ample months left to iron out additional improvements based on the adopted approach.

Reviewer 5:

The reviewer noted that the project has met most of its goals, but not all.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

According to the reviewer, the project is largely a "who's who" of ICME and OEM castings for automobiles. Hopefully, the program will provide something of a standard protocol for development efforts elsewhere.

Reviewer 2:

The reviewer stated that the success in technical accomplishments and the roles of the collaborators are matched. This shows good cooperation.

Reviewer 3:

The reviewer pronounced the team, with industry and academia included, to be very good.

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

Reviewer 1:
The reviewer called for some more compositional work in order to hit all targets. The team seems to have a good grasp on this, and it is reasonable to expect that goals can be achieved.

Reviewer 2:
The reviewer agreed that the future work planned looks to be on a pathway to achieving the original project objectives and goals.

Reviewer 3:
The reviewer supported that the proposed research is to finish out the project.

Reviewer 4:
The reviewer noted that future work is key to the program's overall level of accomplishment and the reviewer wished the team success. It would be more inspiring if there were laboratory-level approaches that were clearly ahead of the property targets, and upcoming engine testing would determine their respective levels of viability. However, the reviewer appreciated that the team is taking a more measured approach and limiting the probability of surprises when they reach the final validation stage.

Reviewer 5:
The reviewer opined that commitment to full component-level validation and a commercialization plan are not evident. Perhaps this was not a contract requirement.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer had no issues with relevance. This project family (increased head performance) is exciting research in that the technology is so close to being ready for the production line. Real results will be available to the consumer in relatively short order.

Reviewer 2:
The reviewer observed that the project descriptions would be stronger if estimates were provided of how much engine efficiency or vehicle fuel economy would result from success with new material.

Reviewer 3:
The reviewer noted that lightweight engine components that meet more stringent requirements to deliver efficiency are a gap. This project begins to address this.

Reviewer 4:
The reviewer agreed that high-strength cylinder heads will enable higher efficiency ICEs, which directly support DOE's objective of petroleum displacement.

Reviewer 5:
The reviewer commented that this research will go a long way toward vehicle lightweighting.

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

Reviewer 1:

The reviewer stated that the group is making solid progress toward the identification of phase structures that will extend performance and stabilize properties. There is still considerable work to be done, but the reviewer was convinced that the direction and progress are within the program's planned schedule.

Reviewer 2:

The reviewer acknowledged that the delay because of the GM foundry was very unfortunate. It probably took out momentum and made the project less efficient. Nonetheless, the team seems to have recovered.

Presentation Number: pm062
Presentation Title: High-Performance Cast Aluminum Alloys for Next-Generation Passenger Vehicle Engines
Principal Investigator: Amit Shyam (Oak Ridge National Laboratory)

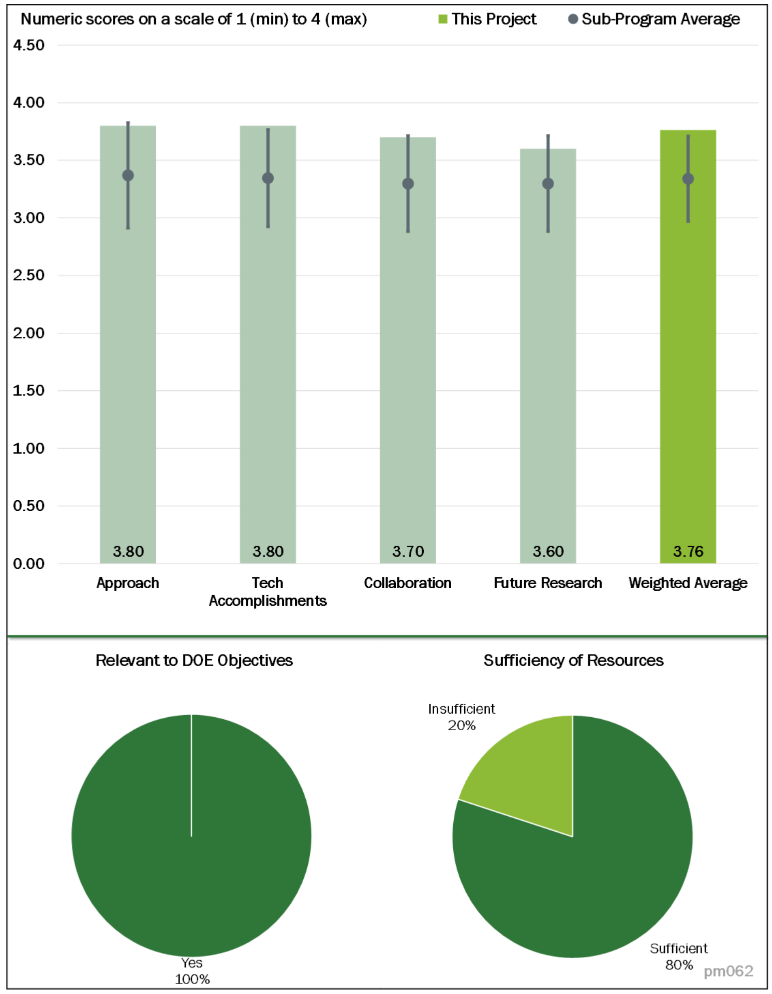

Figure 8-5 - Presentation Number: pm062 Presentation Title: High-Performance Cast Aluminum Alloys for Next-Generation Passenger Vehicle Engines Principal Investigator: Amit Shyam (Oak Ridge National Laboratory)

Presenter

Amit Shyam, Oak Ridge National Laboratory

Reviewer Sample Size

A total of five reviewers evaluated this project.

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

Reviewer 1:

The reviewer pointed out that the program is nearing completion and is presenting extremely promising results regarding project goals. It is difficult to find fault with an exemplary set of preliminary accomplishments. Very little of what the breakthroughs were regarding the modeling and ICME efforts were presented in detail, however, aside from the identification of the rather extraordinary capabilities at ORNL. In truth, all the compelling information presented regarding the newly developed alloys was based on limited mechanical properties testing (which was at face value quite impressive). The list of publications provides some indication, however, that the details in the modeling effort are well documented.

Reviewer 2:

The reviewer stated that the project was logically planned out to meet targets, which clearly emphasized putting together a team with the right partners. The accomplishments under this project clearly indicate the value of the selected approach.

Reviewer 3:

Early on in the project, the reviewer said that the key technical barriers were identified to be high-temperature mechanical properties, castability, and hot tear resistance. Subsequently, following a trial process that was assisted by computational modeling, a new set of alloys was developed that appears to meet or exceed the performance targets set by DOE.

In parallel to the above effort, gaps in our understanding of the material behavior (ICME) are being identified with a view to better develop tailor-made alloys for a given application.

Reviewer 4:
The reviewer found the objectives to be clearly stated. This reviewer noted that engine cylinder heads needed to be improved for temperature improvement and tensile and yield strength improvement (both more than 25%) at higher temperatures (250°C up to 300°C, which the reviewer described as very challenging) at a cost of no more than +10%. The team used the Titan supercomputer at ORNL to process the model and ICME to avoid a time consuming and resource consuming trial-and-error approach.

Reviewer 5:
The reviewer indicated a lack of expertise to comment on the technical approach the researchers are taking.

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

Reviewer 1:
The reviewer stated that the proposed goals have largely been met with few (if any) exceptions outside of validation-level engine testing.

Reviewer 2:
In the reviewer's view, it appears that the researchers are making excellent progress.

Reviewer 3:
The reviewer asserted that the project has resulted in material that has exceeded all targets, some by significant margins. Over the past year, these results have been extended from bench-scale to full-scale components. Fifty cylinder heads have been fabricated with no issues. The project team views the results as representing a superior new alloy family for higher temperature applications. Shortcomings in available analysis models have been identified.

As efforts move toward higher temperature alloys, the PI believes this area will need investment for success.

Reviewer 4:
The reviewer mentioned that the team evaluated a stable microstructure rather than a transient microstructure. This was done by pre-exposing material for 200 hours prior to tensile testing. The alloy AlCuEx - v1 worked best with tensile testing at an acceptable temperature range. Alloy development continued by stabilizing grains to increase strength in creep testing, which allows tailoring of creep resistance. The reviewer also noted thermal conductivity (as high as possible) and hot tear resistance (as low as possible). This reviewer remarked that Alloy AlCuEx - v3 was the version that appeared to be the best of the modified alloys. AlCuEx - v3 was used to fabricate a cylinder head. To date, there was no evidence of cracks in the more than 50 cylinder heads made using the most complicated head design available to the team. There was also very little effect of quenching (water and air) on performance characteristics of the material. The reviewer pointed out that AlCuEx - v3 is a very balanced alloy, and it performs well on all factors—hardness, cost, hot tear resistance, thermal conductivity, and tensile strength. This alloy will be developed into a commercial material by the industry partners for cylinder head and other automotive engine applications.

Reviewer 5:
The reviewer stated that excellent progress has been achieved. A suite of new alloys, AlCuEx, with material properties—castability, hot creep resistance, tear resistance, and high-temperature strength—that exceed the DOE requirements were developed. The remaining targets, such as corrosion resistance, are projected to be addressed next year. While the presentation compares the properties of the alloys developed here with DOE-set goals, the reviewer indicated that sharing the genesis of needing newer casting materials would be helpful.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer noted that the team includes an engine manufacturer, a cylinder head supplier, and experts in manufacturing, casting, and analysis. Team composition has already allowed for transition of project management from ORNL to the industry partner Fiat Chrysler Automobiles (FCA).

Reviewer 2:
The reviewer commented that the collaborative team could not have been better. Each team member has complementary strengths, and the team appears to leverage each other's expertise very well. Overall, this team appears to have the right skills, strengths, and access to facilities to deliver the required high-temperature alloys.

Reviewer 3:
The reviewer observed that industry and national laboratory are well represented, and there is a cooperative research and development agreement (CRADA) with FCA and Nemak USA. This reviewer observed well-defined goals, strong management, ICME, access to a lab supercomputer, and good industry partners achieved excellent results. The Aberration Corrected Electron Microscope was available for use.

Reviewer 4:
The reviewer remarked that casting capabilities and OEM input complement the extensive modeling and test approaches very nicely.

Reviewer 5:
The reviewer stated that it appears that there is strong collaboration with relevant stakeholders.

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

Reviewer 1:
The reviewer stated that the primary remaining efforts are completing the cost analysis and commercialization methodology based upon comparative analyses, both of which are highly necessary pieces to maximize the benefits from the project. The project has identified shortcomings in existing modeling tools.

Reviewer 2:
The reviewer mentioned that most of the barriers (i.e., castability, high-temperature strength, and tear resistance) were adequately addressed. In fact, a number of castings were also performed in association with industrial partners. The proposed future research to assess corrosion resistance and cost is a natural progression of this work. Additional effort to plug any gaps in the ICME model through the knowledge base developed in this effort is laudable.

Reviewer 3:
The reviewer pronounced the proposed future work to be consistent with the current status and the research objectives.

Reviewer 4:
The reviewer commented that it would appear that the program has achieved a rather remarkable breakthrough with regard to developing a cast alloy that meets the target performance levels. Some significant concerns remain, however, particularly regarding the specific knowledge of the program leads regarding the microstructural mechanisms and potential performance debit from an alloy that exhibits a surprising lack of elevated temperature ductility. It may well be moot in an engine that is not designed for any measurable levels

of plastic deformation anyway, but more detail behind the fundamental grounds for the observed mechanical properties would strengthen confidence in the level of success that might be expected from the project discoveries.

Reviewer 5:

The reviewer pointed out that documenting the cost and final report are the only remaining activities. All goals have been accomplished and many exceeded. The project is ending in December 2017, and project leadership is transitioning to industry (FCA) as planned. Commercialization of this alloy is expected to occur at the end of 2017.

ICME gaps still exist in evaluating microstructure evolution. Future work should investigate the integration of microstructure evaluations, which are important as higher temperature performance alloys are developed.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer commented that the project is focused on developing higher performance materials for cylinder heads that allow for more efficient engine operation. This will result in petroleum reductions.

Reviewer 2:

The reviewer noted that the proposed effort leads to identification and development of alloys that can potentially lead to vehicle lightweighting and high-efficiency combustion strategies, which in turn will reduce our petroleum consumption. As a result, this project conforms to DOE's goal of petroleum displacement.

Reviewer 3:

The reviewer responded yes. The results of the project permit higher temperature combustion, which leads to higher efficiency.

Reviewer 4:

The reviewer said that the project enables more efficient operating conditions in ICEs.

Reviewer 5:

The reviewer stated that materials—strength, temperature capabilities, cost, weight, manufacturability—are a limiting constraint to improved engine performance.

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

Reviewer 1:

The reviewer commented that the researchers seem to be on track to meet their program objectives within their allotted budget.

Reviewer 2:

The reviewer opined that funding appears sufficient for remaining efforts.

Reviewer 3:

The reviewer commented that the project was sufficiently funded because the use of the CRADA provided additional needed funding outside of the DOE funding.

Reviewer 4:

The reviewer observed that the results, in principle, speak for themselves.

Reviewer 5:

The reviewer observed that after the initial selection of castable high-temperature alloys, the next phase of work involves assessing machinability, corrosion resistance, and performance of some cast cylinder heads along with their performance on production engines. It might be worth the investment to document and relay this additional knowledge base for others instead of relying on the commercial interests of the industrial partners.

Presentation Number: pm066
Presentation Title: Innovative SCR Materials and Systems for Low-Temperature Aftertreatment
Principal Investigator: Yong Wang (Pacific Northwest National Laboratory)

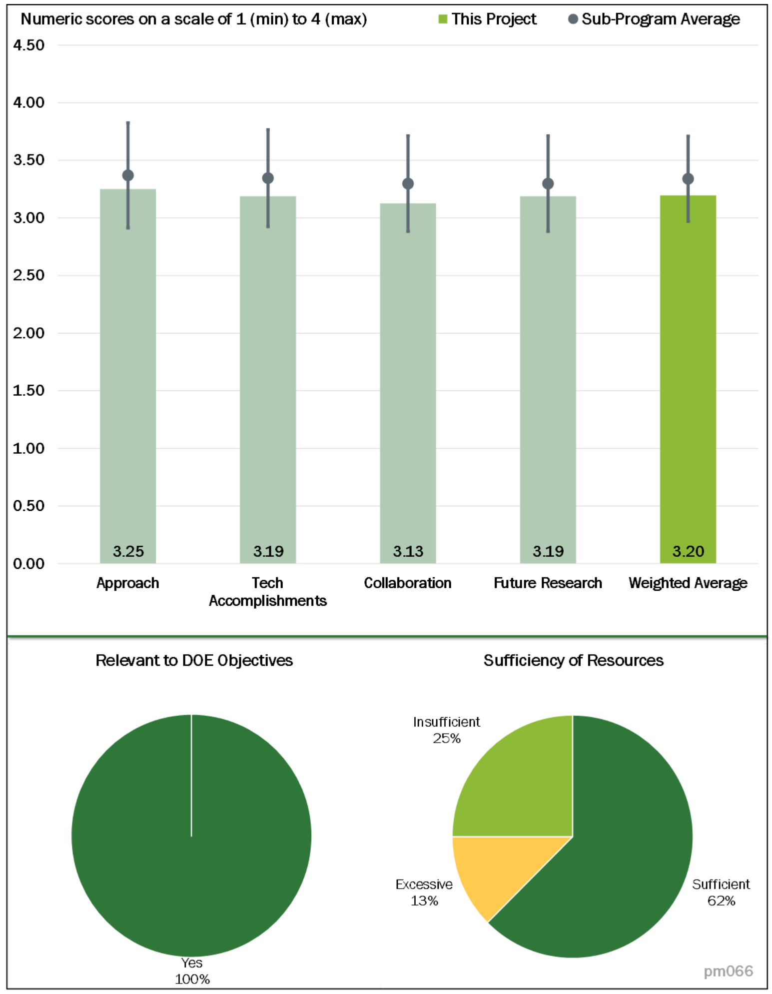

Figure 8-6 - Presentation Number: pm066 Presentation Title: Innovative SCR Materials and Systems for Low-Temperature Aftertreatment Principal Investigator: Yong Wang (Pacific Northwest National Laboratory)

Presenter
Craig DiMaggio, FCA

Reviewer Sample Size
A total of eight reviewers evaluated this project.

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

Reviewer 1:
The reviewer commented that it is very challenging meeting Tier 3 targets. This reviewer reported that this design is being used at ORNL as well. The three-way catalyst (TWC) plus a NO_x storage catalyst (NSC) plus passive selective catalytic reduction barely meet Euro 6 for midsize cars. However, the reviewer observed that impressive progress is being made. The reviewer remarked that the approach of doing new material development, with an eye toward ammonia (NH^3) generation and low-temperature selective catalytic reduction (LT SCR) is certainly reasonable. This reviewer added that aging and engine dynamometer work complete the picture.

Reviewer 2:
The reviewer stated that the approach is focused on improving emission control capability for lean-burn gasoline engines, which is seen as a fuel savings. The project is aiming to generate NH_3 via a TWC or NSC for a downstream SCR catalyst. Major aging mechanisms are included.

Reviewer 3:
The reviewer noted that the scope of the project is very complete and ranges from catalyst development all the way through engine system validation.

Reviewer 4:
The reviewer said very well presented.

Reviewer 5:

The reviewer pointed out that this project focuses on the LT aftertreatment system, which includes a TWC plus NSC placed upstream of an SCR catalyst. Although the capabilities of each component are reasonably well understood, the effectiveness of the total system in LT emission control depends on a lot of factors, including system thermal management and durability characteristics. For example, the TWC plus NSC system can provide additional functionalities beneficial for LT emission control, but their presence in the upstream section will delay the physical warm-up of the SCR catalyst located downstream. Also, conditions required for periodic desulfation process for the NSC (typically in a high-temperature reducing environment) are known to be detrimental to the durability of zeolite-based SCR catalysts. Thus, it seems critically important to direct more efforts toward a system-level approach to the problem (rather than focusing on trying to improve the SCR catalyst, with the NSC formulation and properties considered to be fixed, as indicated or implied in the current project plan).

Reviewer 6:

The reviewer pronounced the approach to the work to be good and strengthened considerably by FCA's ties to the university partner. The strategy for integration is well thought out, if difficult to achieve.

Reviewer 7:

The reviewer agreed that the general approach is technically sound, specifically with a new, second generation catalyst system introduced into the program. Hopefully, the initial results will continue to hold after aging for the future work.

Reviewer 8:

The reviewer opined that the focus of this project—enabling LT SCR catalysis—is important, and the approach is theoretically sound; however, the implementation is less than ideal.

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

Reviewer 1:

The reviewer praised the technical accomplishments as impressive. The team achieved approximately 40 mg/kWh NO_x, which is roughly 10-15 mg/kWh without cold start (a big gap), but on a fresh system. Obviously the high-temperature SCR durability is an issue. The project is ahead of schedule, hitting the milestones more than three months in advance. The second-generation SCR (fresh) achieved 80% conversion at 150°C, just short of the target, for the standard SCR reaction. This is impressive. The TWC plus NSC characterization looks good. The reviewer asked why go for the same de-sulfur oxide (SO_x) temperature. The reviewer pointed out that Mercedes-Benz's commercial lean-gasoline NO_x system has the downstream lean NO_x control (LNC) (not SCR) deSO_x at a lower temperature, the SO_x from the first one passes through. It might be difficult to match a high-temperature LNC with a LT SCR deSO_x, but under rich conditions it might be possible. Obviously, the high-temperature durability gap is critical.

Reviewer 2:

The reviewer called out the excellent progress toward the LT performance goal and how the team is addressing issues as they come up, like deSO_x.

Reviewer 3:

The reviewer said that the project has shown some improvement in hydrothermally aged SCR performance, but only lean, steady state conversion was shown and stoichiometric aging was fairly destructive. There needs to be some element of lean rich aging and a strategy to modify the system or SCR technology to be more robust. A catalyst supplier is now involved to scale-up the SCR catalyst. Nothing was done to address added complexity and on-board diagnostics (OBD) requirements.

Reviewer 4:
The reviewer observed very good results for the second generation catalyst formulation and suggested that the team should continue looking at different aging conditions and amounts of copper.

Reviewer 5:
The reviewer noted that the project has achieved 80% conversion at 150°C and the early results from the second generation of catalyst is somewhat encouraging.

Reviewer 6:
The reviewer observed that some progress has been made in improving LT SCR catalyst performance after hydrothermal aging at 700°C in air, but it is not yet clear whether it will translate into significant improvement in the entire system performance under realistic conditions for the reasons mentioned in the Approach section.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer said that the team is working well together with individual work followed by collective testing.

Reviewer 2:
The reviewer observed that there was good collaboration among Pacific Northwest National Laboratory (PNNL), FCA, and the University of Houston.

Reviewer 3:
The reviewer remarked that the partners seem engaged in the project, including an OEM, national laboratory, and university. A catalyst supplier is now involved but was not identified.

Reviewer 4:
The reviewer noted primarily PNNL activities so far, with some contribution from University of Houston. The reviewer did not see clear synergy between PNNL and the university activities and proposed careful, system-level assessment of the project concept and strategy, perhaps by FCA and/or the University of Houston, sooner than later in order to identify the primary paths to maximize the LT emission performance of the entire system under realistic operating conditions of lean-burn gasoline engines.

Reviewer 5:
The reviewer stated that the program would be stronger if it can get a direct partner from a catalyst supplier.

Reviewer 6:
The reviewer suggested that the collaboration with the catalyst expert should be clearer.

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

Reviewer 1:
The reviewer commented that future plans hit all the most critical remaining questions.

Reviewer 2:
The reviewer stated that future plans cover what the project team needs to achieve for the program goal shown in Slide 21.

Reviewer 3:

The reviewer stated that future work is nicely focused on the right parameters, but suggested that the team may wish to consider adding a small urea system. If the NSC can take down NO_x and generate NH_3, the urea system size might be manageable.

Reviewer 4:

The reviewer remarked that there was a need to address the lean versus rich aging of SCR catalysts. Another need is to address the additional cost and complexity of a lean NO_x strategy for lean-burn gasoline, and if the OBD requirements make it unfeasible given the potential savings in fuel economy by going lean.

Reviewer 5:

The reviewer recommended that the team show fast and standard SCR reactions with a second generation catalyst similar to that of the first-generation catalyst. The team should continue to optimize the amount of copper that needs to be added to the SCR catalyst while looking at different aging conditions.

Reviewer 6:

The reviewer wanted to see future efforts directed more toward system-level performance and durability issues, as pointed out in the Approach section.

Reviewer 7:

The reviewer commented that future work, especially regarding the alternative catalyst, seems ambitious given the time remaining in the project. There is significant durability work remaining, which seems to be a more important area to focus on.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer pointed out that emission controls are mandatory enablers for developing and emerging high efficiency engines.

Reviewer 2:

The reviewer stated that lean gasoline control has gaps being addressed here.

Reviewer 3:

The reviewer observed that LNC technology is an enabler for higher efficiency engine using lean burn.

Reviewer 4:

The reviewer said yes, improving catalyst efficiency has a direct tie to improving fuel efficiency.

Reviewer 5:

The reviewer acknowledged that lean gasoline engines, the intended application for this project, offer better fuel economy than conventional stoichiometric gasoline engines, but one of the barriers for mass production is emission control.

Reviewer 6:

The reviewer said that achieving 150°C light-off temperature is part of the DOE program objectives.

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

Reviewer 1:

The reviewer stated that, for what is being accomplished and the planned accomplishments, the funding is low by about 50%.

Reviewer 2:
The reviewer stated that resources seem sufficient. Most of the money is going to PNNL.

Reviewer 3:
The reviewer noted that the project team is ahead of schedule.

Reviewer 4:
The reviewer said yes, and wanted to see more involvement (or documented involvement) from the catalyst expert.

Reviewer 5:
The reviewer asserted that the project team gets what is needed.

Reviewer 6:
The reviewer commented that PNNL is funded in multiple ways for the same work. [DOE Program Clarification: PNNL has two teams working on NO_x reduction technologies, one with a LD engine company that is using lean gasoline combustion, and the other is working on low-temperature HD diesel exhaust. The exhaust compositions from the two systems are significantly different and the research of the two PNNL teams is separate and unique. There is no duplication.]

Reviewer 7:
The reviewer understood that the University of Houston has a modeling capability of individual components involved (e.g., TWC, NSC, and SCR). However, the reviewer was not sure they are able or willing to jump into the systems-level modeling and analysis that this project needs.

Presentation Number: pm067
Presentation Title: Next-Generation Three-Way Catalysts for Future, Highly Efficient Gasoline Engines
Principal Investigator: Christine Lambert (Ford Motor Co.)

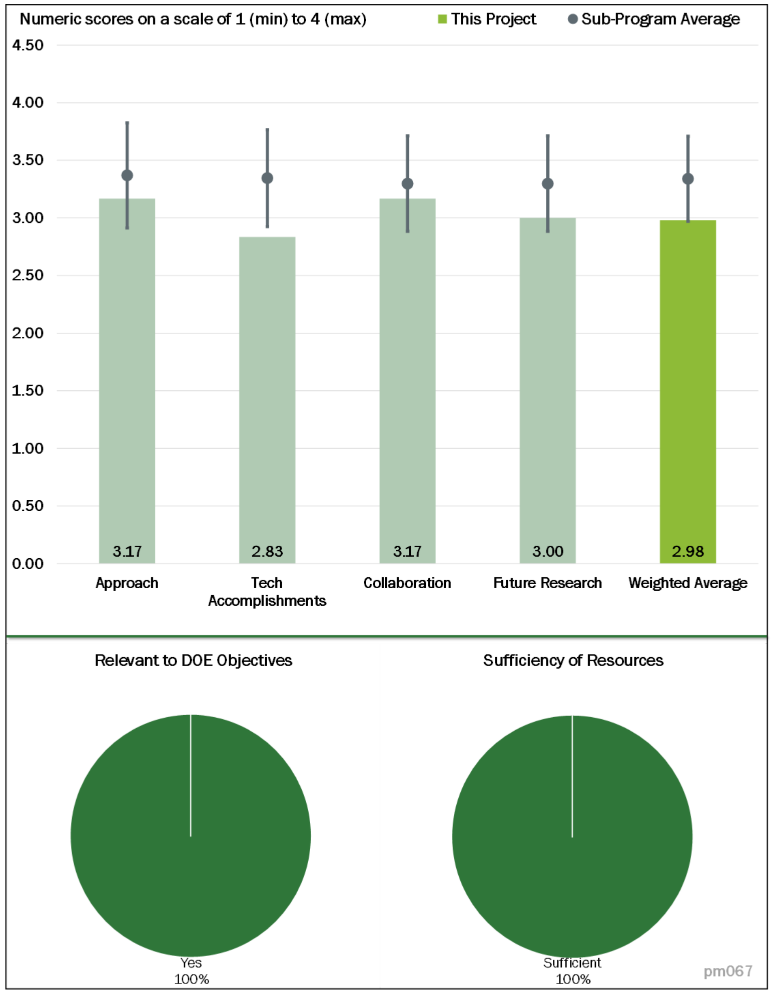

Figure 8-7 - Presentation Number: pm067 Presentation Title: Next-Generation Three-Way Catalysts for Future, Highly Efficient Gasoline Engines Principal Investigator: Christine Lambert (Ford Motor Co.)

Presenter

Christine Lambert, Ford Motor Co.

Reviewer Sample Size

A total of three reviewers evaluated this project.

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

Reviewer 1:

The reviewer said that the project is near completion and significant progress bears out the excellent approach taken.

Reviewer 2:

The reviewer commented that this project plan has been well-designed and executed in a systematic manner in cooperation with multiple partners who brought in their own unique capabilities. The performance evaluations were done under realistic simulated exhaust conditions after catalyst aging under well-accepted temperature and air-fuel ratio conditions for stoichiometric gasoline engines.

Although the catalyst aging protocol used in this study includes some lean high-temperature exposure, it would have been more assuring if the promising rhodium-based candidate catalysts had been aged under more lean-biased conditions (i.e., at leaner air-fuel ratios and/or for longer periods of lean time) before performance testing. A reason for this view is that TWCs for future "stoichiometric" gasoline engines will likely be exposed to high-temperature lean operations, such as deceleration, fuel cuts, and stop-starts more frequently for improved fuel efficiency.

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

Reviewer 1:

The reviewer noted that the findings of this project may have important implications for alternative and next-generation three-way catalyst formulations, prompting serious consideration of rhodium as a major active component for three-way catalysts. It is rather surprising and interesting to see how much rhodium (at relatively low loading) can do in the catalytic control of the three major pollutants in exhaust (especially hydrocarbon conversion) at low temperatures.

Reviewer 2:

The reviewer stated that the project made good progress toward the goal of 150°C activity but did not hit the full target.

Reviewer 3:

The reviewer said that there was good progress toward reaching the 150°C light-off goal, but there is still a ways to go to actually reach the goal.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:

The reviewer stated that collaboration with other institutions is generally good, but can be improved. It is good that Johnson Matthey has been involved to guide manufacturing feasibility and cost estimates of the new catalyst preparation and formulation concepts investigated in the project.

Reviewer 2:

The reviewer found that the team covered all key scales, from microscopic to full-scale devices using different team members: universities to commercial catalyst companies.

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

Reviewer 1:

The reviewer pointed out that the project is near completion, but it shows very good final steps of evaluation and consideration for commercialization.

Reviewer 2:

The reviewer stated that this project is very near the official ending date of September 30, 2017. It would have been nice to have feedback and guidance from Johnson Matthey regarding manufacturability and costs associated with possible large-scale production during the remainder of the project period.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:

The reviewer noted that advanced gasoline engines are potential petroleum savers in many markets and rely on cost-effective TWC aftertreatment.

Reviewer 2:

The reviewer stated that improved TWCs have a very broad application across the whole of the automotive space, and will directly impact vehicle efficiency.

Reviewer 3:

The reviewer asserted that this project addresses itself to an important problem of developing TWCs with improved LT activity, which is a critical enabler for next-generation fuel-efficient vehicles.

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

Reviewer 1:
The reviewer commented that with about four months remaining, the project status is approximately 90% complete and has completed downselecting promising candidate catalyst formulations.

Presentation Number: pm068
Presentation Title: Sustained Low-Temperature NO_x Reduction (SLTNR)
Principal Investigator: Yuhui Zha (Cummins)

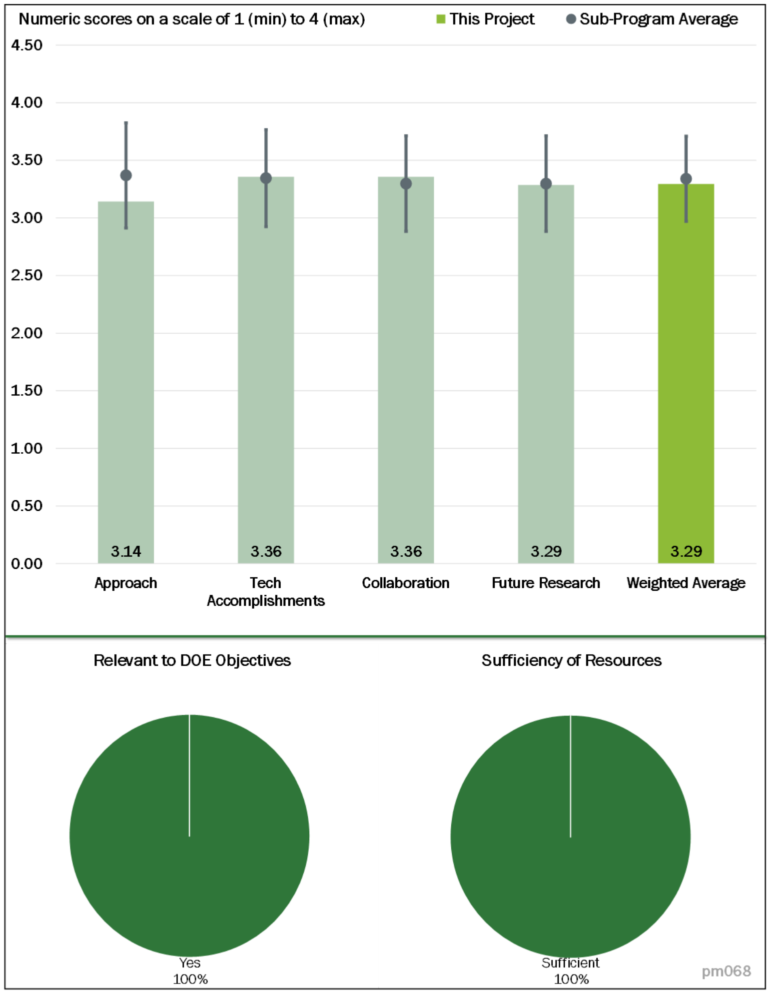

Figure 8-8 - Presentation Number: pm068 Presentation Title: Sustained Low-Temperature NOx Reduction (SLTNR) Principal Investigator: Yuhui Zha (Cummins)

Presenter
Yuhui Zha, Cummins

Reviewer Sample Size
A total of seven reviewers evaluated this project.

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

Reviewer 1:
The reviewer commented that the approach of identifying a suitable catalyst, delivering nitrogen dioxide (NO_2) and getting LT urea was successful. It was not easy and all the issues seem to have been addressed and evaluated.

Reviewer 2:
The reviewer said that the project approach was appropriate.

Reviewer 3:
The reviewer mentioned that the approach is sound and addresses both LT catalysis and LT urea delivery, which makes the research comprehensive and believable.

Reviewer 4:
The reviewer asserted that there is a strong approach to this project, with excellent focus on current, near-term, and long-term issues. There is very good collaboration among Cummins, PNNL and Johnson Matthey, all of which had clear roles. It would have been nice to see a university partner included as well.

Reviewer 5:
The reviewer found the approach to be is good, but a monster system shown in Slide 16 is a major concern because of cost and packaging issues.

Reviewer 6:
The reviewer found the approach to be satisfactory—and it could have been good to very good—but there seems to be a key gap in the catalyst materials story. Laboratory testing of sustained low-temperature NO_x reduction (SLTNR) A and B powders at 150°C and 175°C showed promise. However, it was somewhat surprising to not see any study of the conversion efficiency of powders A and B after aging at higher temperatures representative of the broader duty cycle. Such an aging study, as a key metric of materials quality

and stability, would have substantially elevated confidence in the potential for success of this approach. The importance of addressing this temperature stability issue should have at least been acknowledged in the presentation as many catalyst materials perform much differently after initial higher temperature exposure or after extended time at higher temperatures. If such work is not in progress yet—and the reviewer suspected that it is knowing the quality of this team—the reviewer strongly recommended that step prior to engine testing.

Testing at various NO_x fractions was performed, which was appropriate. But, it might be helpful for next year's reviewers (not all of whom will have a significant background in aftertreatment systems) to see the anticipated range of actual NO_x levels for engine operation.

As a minor administrative note, the structure of Slide 9 is extremely frustrating for a reviewer as the text is incredibly small!

The diesel emission fluid (DEF) vaporizer study was curious. It was encouraging to see off-the-shelf items being used, although it was somewhat difficult to imagine such a system being re-designed for deployment for a million plus miles on road. The fact that the system degraded in a few days was of concern, but the ability to regenerate provides optimism.

The risk assessment, as presented, was not particularly effective for a reviewer to analyze. The overall approach was good, but there were some curious gaps.

Reviewer 7:

The reviewer stated that barriers as presented did not match Propulsion Materials area barriers.

The sustainability of a high NO_2 strategy should be included. Catalysts that generate NO_2 also tend to generate more nitrous oxide (N_2O) and also oxidize sulfur. This could have long-term effects on both the catalyst system durability and the greenhouse gas emission of the system.

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

Reviewer 1:

The reviewer exclaimed that they project team did it. The reviewer was pleased that the team hit the goal on an engine dynamometer, and the long-term feasibility looks okay. The reviewer remarked well done, and looked forward to the vaporizer results.

Reviewer 2:

The reviewer commented that the results with NH_3 to achieve the project goal were excellent, as was the vaporizer that was developed to be used with DEF.

Reviewer 3:

The reviewer noted that the urea vaporizer is very interesting. This could be a viable way to use existing DEF infrastructure with a new dosing system capable at lower temperatures.

Reviewer 4:

The reviewer mentioned that the researchers have met the goal of delivering urea at LT through the design of a novel vaporizer and used this to enable a LT SCR to reduce NO_x emissions by 90%.

Reviewer 5:

The reviewer said there had been excellent progress toward project completion.

Reviewer 6:
The reviewer remarked that the results look good, but the system is too complicated. It is hard to imagine which vehicle can have a room to install such a complicated system, as shown in Slide 16, not mentioning the cost.

Reviewer 7:
The reviewer observed that the goals for this project are difficult so it is encouraging to see the reported progress. However, the long-term stability of multiple systems still seems questionable or unknown in year 3 of the study, which is of particular concern in HD engines with very long service lifetimes. Thus, more emphasis on the impact and challenges of time and temperature would give a much clearer picture of the potential of the approaches selected.

Question 3: Collaboration and coordination with other institutions.

Reviewer 1:
The reviewer asserted that the collaboration obviously worked. Catalyzer, OEM, and PNNL are a winning team. In fact, the team is delivering more than expected.

Reviewer 2:
The reviewer opined that the close relationships among Cummins, Johnson Matthey, and PNNL are apparent.

Reviewer 3:
The reviewer said it seemed appropriate.

Reviewer 4:
The reviewer observed that having a national laboratory and a catalyst supplier as partners are really helpful.

Reviewer 5:
The reviewer stated that the three-way collaboration appears to be effective although the specific contributions of Johnson Matthey to date were not quite clear.

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

Reviewer 1:
The reviewer noted that the project will close with not only meeting objectives, but with additional deliverables. As all the future work is bonus, the reviewer said "outstanding."

Reviewer 2:
The reviewer asserted that more work on sulfur effects (catalyst poisoning, sulfate emissions, and effect on the downstream SCR catalyst) needs to be included. There is also a need to measure N_2O under more operating conditions.

Reviewer 3:
The reviewer found the work to be well documented and suggested that the team consider a comparison of NH_3 SCR at these low temperatures versus DEF vaporizer at these low temperatures.

Reviewer 4:
The reviewer stated that the proposed research is to finish out the project by evaluating the durability of the LT catalysis system.

Reviewer 5:
The reviewer remarked that there is still a lot of work to do for a commercially viable project.

Reviewer 6:
According to the reviewer, realizing the packaging is an issue is a good start for the future work, but the reviewer was not sure how it can reduce the system size significantly.

Reviewer 7:
The reviewer stated that the project is in its final year and moving toward an engine test, which is very encouraging. However, it seemed that a number of essential materials durability and stability issues (including longer-term durability of a regeneration cycle in the pre-turbo diesel oxidation catalyst) remain and at a reduced funding level for year 3 as compared to the previous year. It is of concern to see that temperature stability, hydrocarbon effects, and sulfur effects have not yet been examined for the key SCR materials. If there are issues, there will be little time to redesign materials prior to assembly and testing of the engine.

Question 5: Relevance—Does this project support the overall DOE objectives of petroleum displacement?

Reviewer 1:
The reviewer stated that the ability to significantly improve lower-temperature NO_x reduction in a HD engine will be of enormous value in enabling higher efficiency engine concepts that result in lower exhaust temperatures.

Reviewer 2:
The reviewer pointed out that reducing urban, low-load NO_x costs fuel for thermal management and this approach saves most of loss.

Reviewer 3:
The reviewer stated that the project supports aftertreatment of more efficient diesel engines with lower exhaust temperatures.

Reviewer 4:
The reviewer said yes. Improving NO_x conversion efficiency by means of an SCR catalyst has a direct link to improved fuel efficiency.

Reviewer 5:
According to the reviewer, the more efficient the diesel engine is, the lower the exhaust temperature is. Because the engine cannot be sold without its meeting emissions regulations, the LT catalyst is needed to reduce petroleum use.

Reviewer 6:
The reviewer noted that achieving 150°C light-off temperature is part of DOE objectives.

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

Reviewer 1:
The reviewer noted that the program goals were met ahead of time, with resources to spare for bonus work. The reviewer proposed that the team use the remaining funding for this work.

Reviewer 2:
The reviewer commented that the 50-50 cost share with Cummins indicates resources are sufficient for the scope as defined.

Reviewer 3:
The reviewer said yes.

Reviewer 4:
The reviewer reported that the team has what it needs.

Acronyms and Abbreviations

AlCuEx	Aluminum copper alloy
CGI450	compacted graphite iron 450
°C	Celsius
CFD	Computational fluid dynamics
CRADA	Cooperative research and development agreement
DEF	Diesel emission fluid
$DeSO_x$	de-sulfur oxide
DOE	U.S. Department of Energy
FCA	Fiat Chrysler Automobiles
FEM	Finite element modeling
GM	General Motors
HD	Heavy-duty
ICE	Internal combustion engine
ICME	Integrated Computational Materials Engineering
L	Liter
LD	Light-duty
LNC	Lean NO_x catalyst
LT	Low temperature
LT SCR	Low-temperature selective catalytic reduction
MYPP	Multi-Year Program Plan
N_2O	Nitrous Oxide
NH_3	Ammonia
NO_x	Nitrogen Oxide
NO_2	Nitrogen Dioxide
NSC	NO_x storage catalyst
OBD	On-board diagnostics
OEM	Original equipment manufacturer

ORNL	Oak Ridge National Laboratory
PI	Principal investigator
PNNL	Pacific Northwest National Laboratory
RT	Room temperature
SCR	Selective catalytic reduction
SLTNR	Sustained low-temperature NO_x reduction
TWC	Three-way catalyst
VTO	Vehicle Technologies Office