

## 8. High Efficiency Clean Combustion and Enabling Technologies

### Introduction

High Efficiency Clean Combustion and Enabling Technologies involves development of critical technologies necessary for achieving DOE VT goals for efficiency in advanced combustion engines. Enabling technologies work focuses on fuel systems, engine control systems, and engine technologies. Fuel systems R&D focuses on injector controls and fuel spray development. Engine control systems R&D focuses on developing engine controls that are precise and flexible for enabling improved efficiency and emission reduction in advanced combustion engines. Engine technologies development will be undertaken to achieve the best combination that enables advanced combustion engines to meet maximum fuel economy and performance requirements. These include variable compression ratio, variable valve timing, variable boost, advanced sensors, and exhaust emission control devices (to control hydrocarbon emissions at idle-type conditions) in an integrated system.

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

Page	Project Title and Principal Investigator	Project Average Score	Project Score Standard Deviation
8-4	Advanced Boost System Development for Diesel HCCI Application (Harold Sun, Ford Motor Company)	3.00	0.63
8-7	Development of a Robust Accelerometer- Based Start of Combustion-Sensing System (Jim Huang, Westport Innovations)	4.20	0.63
8-11	Development of Enabling Technologies for High- Efficiency, Low-Emissions HCCI Engines (David Milam, Caterpillar, Inc)	3.09	0.83
8-15	Enabling High-Efficiency Clean Combustion (HECC) (Don Stanton, Cummins Inc.)	3.79	1.05
8-19	Engine System Approach to Exhaust Energy Recovery (Rick Kruiswyk, Caterpillar Inc.)	3.14	0.69
8-22	Exhaust Energy Recovery (Chris Nelson, Cummins Inc.)	3.50	0.76
8-25	Heavy Truck Engine Development and HECC (Houshun Zhang, Detroit Diesel Corporation)	3.50	0.90
8-28	HECC Engine Designs for Spark-Ignition and Compression-Ignition Engines (Ken Patton, General Motors Corporation)	3.62	0.77
8-31	Light-Duty Efficient Clean Combustion (Tim Frazier, Cummins Inc.)	3.70	0.82
8-35	Low-Cost, Fast Response Actuator (Charles Mendler, Envera LLC)	3.00	1.08
8-39	Low-Temperature Combustion Demonstrator for High-Efficiency Clean Combustion (Willy Ojeda, Navistar Inc.)	3.33	1.12

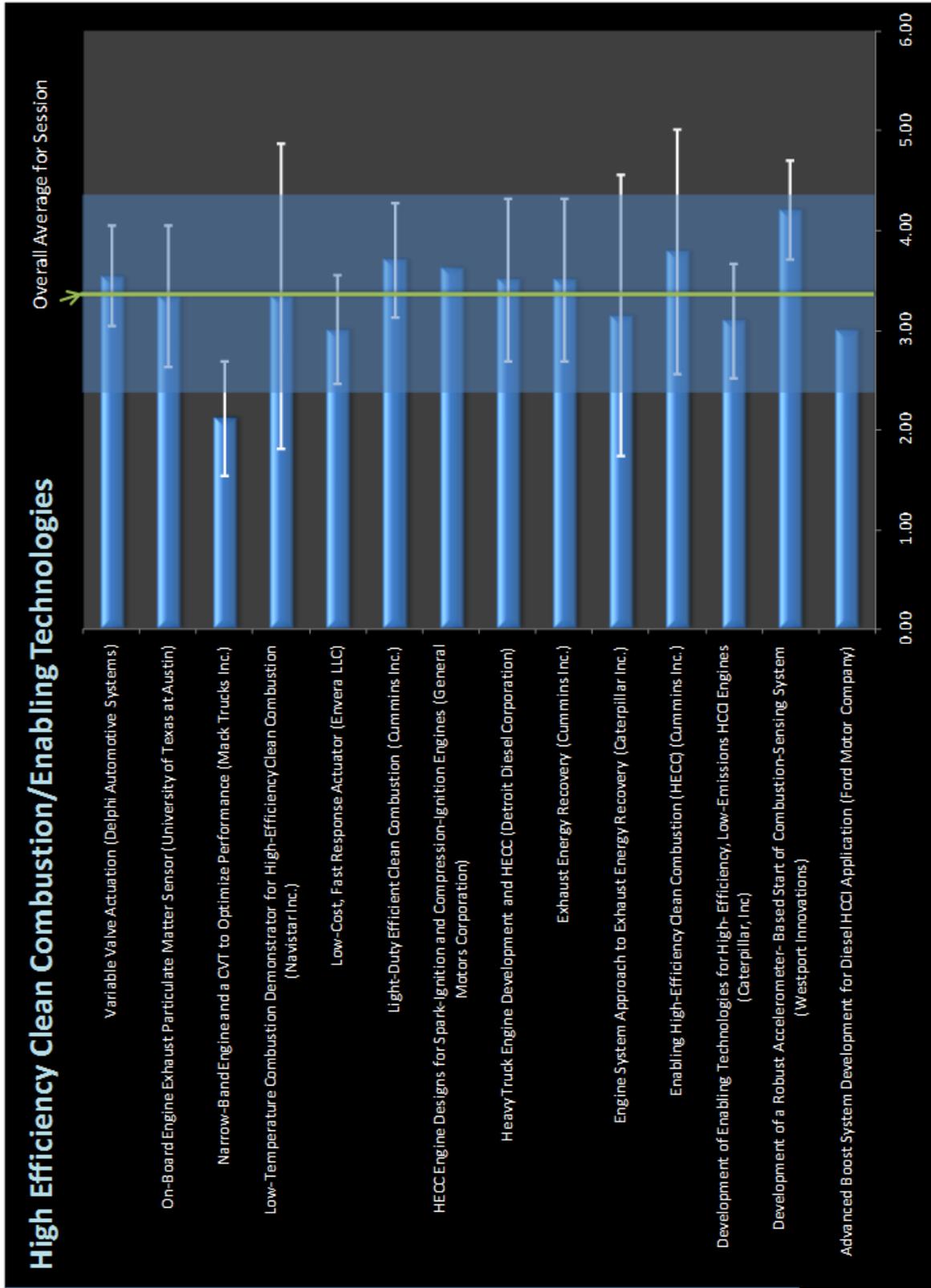


## 2008 Annual Merit Review

### DOE EERE Vehicle Technologies Program

Page	Project Title and Principal Investigator	Project Average Score	Project Score Standard Deviation
8-43	Narrow-Band Engine and a CVT to Optimize Performance (Bahman Habibzadeh, Mack Trucks Inc.)	2.11	0.60
8-47	On-Board Engine Exhaust Particulate Matter Sensor (Matt Hall, University of Texas at Austin)	3.33	1.07
8-51	Variable Valve Actuation (Jeff Gutterman, Delphi Automotive Systems)	3.54	1.05
<b>Overall Session Average and Standard Deviation</b>		<b>3.38</b>	<b>0.97</b>





### Advanced Boost System Development for Diesel HCCI Application (Harold Sun, of Ford Motor Company)

#### Reviewer Sample Size

This project had a total of 6 reviewers.

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

One reviewer stated that improved turbocharging efficiency will be an important component development for reducing fuel use for various LTC combustion regimes. Another noted that HECC technology is planned, enabled by a focus on the air-plug-EGR handling system. One other person commented that the air system handling is basic and important to improving engine thermal efficiency. Improving turbocharger efficiency can reduce engine back pressure and PMEP.

One reviewer stated that this looks like a good program to support LTC advancement. However, little work has been published on how the turbocharger system fits into, can enhance, or hinder the LTC combustion concepts. One final reviewer stated that he or she is not sure that the turbo project alone can achieve the DOE objectives due to the issues mentioned below and despite the technical justification provided.

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

The first reviewer indicated that this project is just getting started, while another added that this is difficult to assess at this stage of the project. One person added that the project is in its very early stages and available options for turbo design should be more flexible – otherwise it merely becomes an exercise in building a pre-designed piece of equipment.

One reviewer commented that redesigning/modifying a current TC to match an engine is a direct approach to reach the target. However, it will be challenging to design a TC considering both LTC mode and other modes. One person added that the group needs to engage turbo supplier(s) soon to get feedback on incorporating these methods on small turbos. One final reviewer added that he or she is not sure if Ford is in a position to deploy results from the analysis – seems that a turbocharger partner may be advantageous to the program. For example, if the full turbo system does not work, minor advances may not be adopted into real hardware without a turbocharger partner. Additional barriers exist involved in the details of matching compressor/turbine, and classical equations are not sufficient for this. Detailed flow effects and pulsation will have a large influence on the actual testing result. This reviewer thinks the turbocharger/air system alone is not sufficient. There should be a large effort to adapt the engine/air system for the matching effort traditional to any development project.

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

Multiple reviewers indicated that the project is new and has not developed results yet. One reviewer added that detailed planning was shown however, while another person said that the project is on its plan. One final reviewer added that this project is just getting started, but barriers in developing a boost system that meets overall efficiency seem to be well understood. This reviewer added that the timeline shown for the project seems too long.



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

The first reviewer commented that Ford has the internal resources needed to enable it to bring this advanced boost system into the marketplace, while another person noted that Ford is an OEM, so taking this to production is relatively easy. One reviewer stated that matching turbocharger performance to the new combustion regimes will be a key enabler to meeting emission and efficiency targets. One other respondent remarked that component development such as this usually finds its way into production if the results of the work are good enough, and if it fits the company's product plans.

One final reviewer is not sure if Ford is in a position to deploy results from the analysis – seems that a turbocharger partner may be advantageous to the program. For example, if the full turbo system does not work, minor advances may not be adopted into real hardware without a turbocharger partner. Additional barriers exist involved in the details of matching compressor/turbine – classical equations are not sufficient for this. Detailed flow effects and pulsation will have a large influence on the actual testing results.

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

One reviewer commented that there seems to be an appropriate level of planned accomplishment for the moderate funding level this project received in FY08.

To contrast, one person stated that he or she thinks resource efficiency would improve with the input of a turbomachinery supplier or other expertise. Another commented that there is a very long timeline for this project. This reviewer wanted to know how much input was being contributed from the turbo companies. One other reviewer indicated that there seems to be excessive subsidization of something that the company should develop on its own if it is very critical to the company's future product plans. If it is not central to the future product plans, then it should not be pursued or funded by DOE.

One final reviewer noted that the Cummins project and Ford project have the same level of funding. However, this Ford project only described the development of an advanced boost system for HECC/HCCI/LTC combustion. Is the existence of a HECC engine assumed? If so, then why the high level of funding? If not, then why was nothing presented on the development of an engine?

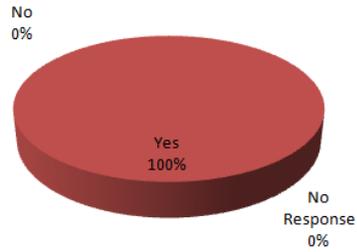
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

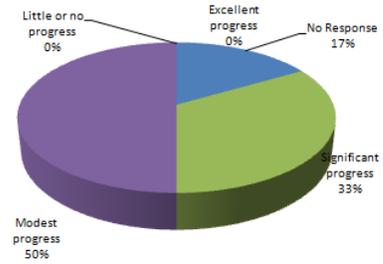


**Project: Advanced Boost System Development for Diesel HCCI Application**

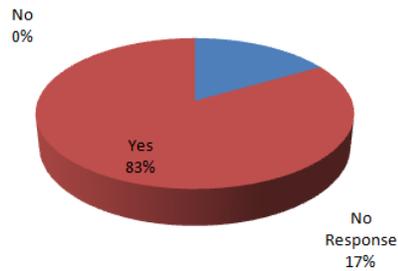
**Question 1: Does this project support the overall DOE objectives of petroleum displacement?**



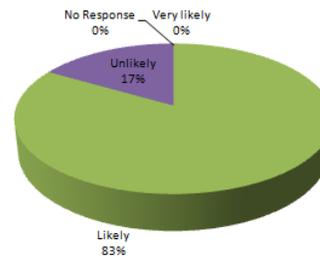
**Question 3: Characterize the technical accomplishments and progress toward goals.**



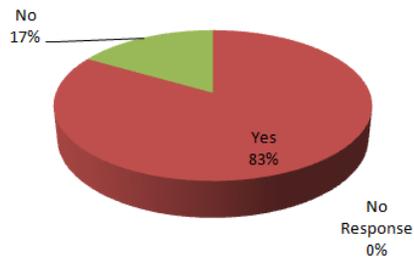
**Question 2a: Are the goals of the project technically achievable?**



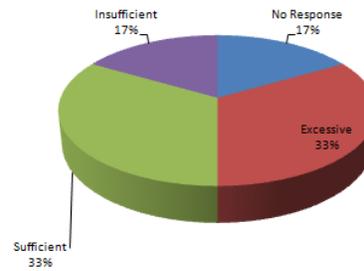
**Question 4: How likely is the project team to move technologies into the marketplace?**



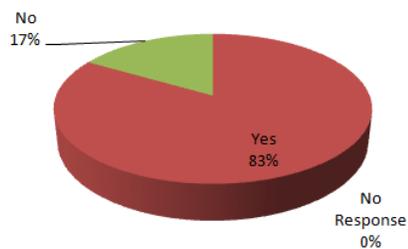
**Question 2b: Have the technical barriers been identified and addressed?**



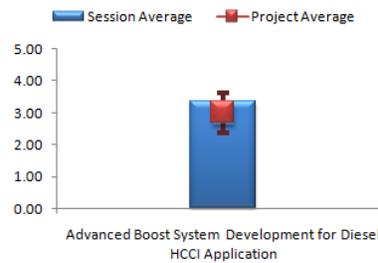
**Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.**



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



**Question 6: Overall Rating**



## Development of a Robust Accelerometer- Based Start of Combustion-Sensing System (Jim Huang, of Westport Innovations)

### Reviewer Sample Size

This project had a total of 10 reviewers.

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

One reviewer stated that the start of combustion is an important piece of information for LTC and other alternative combustion modes, which in turn are important for reduction of future fuel use. One person commented that using knock sensor to predict combustion and recovery in-cylinder pressure has a lot of potential for improving engine combustion and combustion control. Another commented that this is an enabling technology for HCCI and LTC, while one other reviewer added that this is an enabling technology for advanced combustion techniques, perhaps, and also for basic OBD2 requirements for light-duty diesel. One respondent indicated that SOC combustion sensors are needed to enable HECC and other advanced combustion concepts.

Two reviewers stated that it served DOE goals indirectly, with one adding that an improvement in efficiency can be gained if the sensor can be used to compensate for variations in fuels, engine-build tolerances, or operating conditions. One final reviewer stated that this project will indirectly support DOE fuel economy improvement goals through the use of a combustion sensor to better control the combustion event and thus allow for further optimization of the engine thermodynamic cycle from a break thermal efficiency viewpoint. This sensor (if successful) will have a small impact, but if integrated with other technologies it could make a noticeable difference.

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

Multiple reviewers commented on the good technical approach of the project. One person noted that some of the results show the approach is viable, while another reviewer stated that the barriers are well understood, and most of the remaining work involves improving the robustness and durability of the sensor. One other individual suggested that the project is nearing its end (contrary to other reviewers) and seems to have been successful.

One response remarked that there have been good results considering the recent start and very low level of funding. Westport is in a good position to implement the technology with a range of OEMs. Another reviewer stated that the technology looks to be close to deployment readiness. This reviewer agrees that this technology would be a more desirable combustion monitoring system than an in-cylinder sensor, and this makes it a likely candidate for deployment. However, it needs to be especially robust, since the need to access the main bearing caps does lend itself to replacing the sensors very easily. One other reviewer indicated that there is a need to address accuracy with a less-than-full complement of sensors. For cost reasons, fewer sensors are better.

One person asked what approach is planned to determine the transfer function of the piston/rod/bearing assembly. One final reviewer said the initial results have been very promising, but the sensor-to-sensor and engine-to-engine accuracy will be difficult to overcome considering the power cylinder dynamics will vary from engine to engine.



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

One reviewer commented that very little time has passed so far, so the results are impressive. There is good attention to the appropriate level of details, including error levels and statistical variation. Another person stated that there was good progress for the first year, and the goals were met very quickly. This reviewer is not sure where the goal of 0.5 deg CA standard deviation was derived from – did it come from Cummins? One reviewer noted that some data prove the assessment, while another person remarked that the initial results that show correlation to lab grade cylinder pressure measurements are encouraging to say the least. Much additional work is needed to further quantify the reliability and durability of this sensor and its use for engine control within a real world engine environment.

One person felt that the project is nearing its end and seems to have been successful. One reviewer noted that the SOC error target was achieved, the engine-to-engine standard deviation error of less than 0.5 deg CA was achieved, and the sensor-to-sensor standard deviation error of less than 0.5 deg CA was achieved. One final reviewer stated that they have already demonstrated some of their goals and are now looking at 'bonus' goals.

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

The first reviewer stated that Westport seems interested in using this technology and so needs to find a third party to develop a commercially hardened version of this sensor and its accompanying electronics/computational hardware. Other OEMs should be interested too - it just depends on whether they know where to look or are indeed looking. Another person suggested that the group keep working to get some OEMs interested in this and hearing their feedback. One reviewer said this program will require substantial additional financial resources for transition to occur unless a sensor OEM decides to co-fund or fund this effort. Though the initial results are promising, it seems unlikely that an OEM would invest the millions of dollars necessary to develop this sensor for engine control.

Another respondent remarked that this is a much needed sensor for enabling advanced combustion. However, what needs to be added to the program scope is the development of the sensor for HECC/HCCI/LTC and dilute gasoline stratified-charge combustion engines. This seems like this will be an excellent project for the next phase of sensor development. One response commented that the sensor has a wide application in engine industry if successful, but the author needs to address the following issue: (1) signal sensitivity to the sensor location and (2) signal sensitivity to the gap in bearing.

One reviewer remarked that this is a high risk/high reward element to support advanced combustion techniques. OBD2 has a direct application for misfire control for example – but there are other monitors as well. One final reviewer stated that, if this is durable and information beyond SOC can be determined, then this could be an enabler for alternative combustion regimes.

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

Multiple reviewers commented that this is a good use/great value of limited DOE funding, and that it is a very modestly funded project. One reviewer noted the very low funding level \$55K, adding that this project shows good potential results in a high potential ROI. Another person suggested more resources for validation on a variety of conditions/engines.



One reviewer asked if the knock sensor suppliers have been engaged. These sensors are not usually used in the crankcase and may need significant modification to be sufficiently durable. Another response indicated that this project needs additional experimental resources such as another engine or engines for evaluation. This project also needs some type of engine control element. One final reviewer stated that given the scope of the project, and if demonstration of other engines as described above is added and benchmarked against a similar project (such as the on-board engine exhaust particulate matter sensor project at University of Texas at Austin), a modest increase is justified.

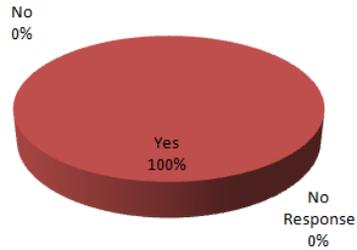
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

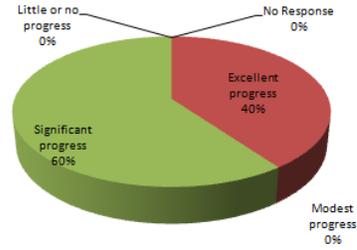


**Project: Development of a Robust Accelerometer- Based Start of Combustion-Sensing System**

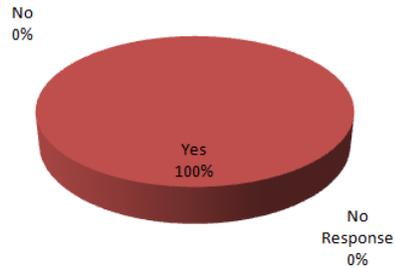
*Question 1: Does this project support the overall DOE objectives of petroleum displacement?*



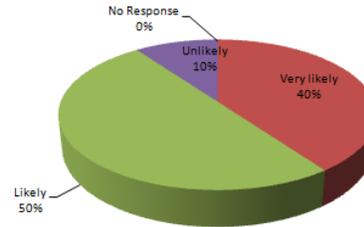
*Question 3: Characterize the technical accomplishments and progress toward goals.*



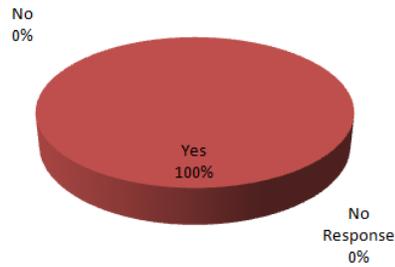
*Question 2a: Are the goals of the project technically achievable?*



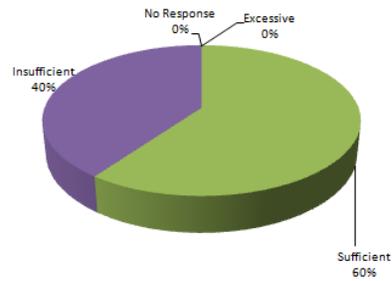
*Question 4: How likely is the project team to move technologies into the marketplace?*



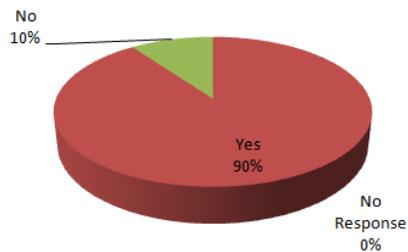
*Question 2b: Have the technical barriers been identified and addressed?*



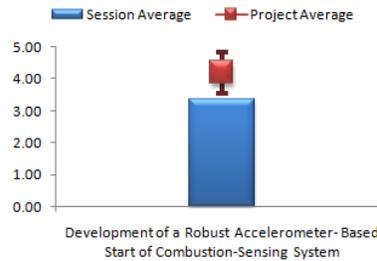
*Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.*



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



*Question 6: Overall Rating*



## Development of Enabling Technologies for High- Efficiency, Low-Emissions HCCI Engines (David Milam, of Caterpillar, Inc)

### Reviewer Sample Size

This project had a total of 12 reviewers.

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

Multiple reviewers pointed to the resulting increased efficiency, with one reviewer adding that the group is moving forward with the development and demonstration of efficiency improvements in HD diesel engines. Another person commented that the work is well-aligned with objectives of improving fuel economy while satisfying emissions constraints. One response stated that the identified goal of achieving a 10% BTE improvement is in line with DOE objectives. One other reviewer remarked that a low emissions, high efficiency, production viable, low-temperature combustion engine system is the most effective way.

One reviewer commented that heavy truck users have a vested interest in technologies which improve fuel economy or reduce cost, as there is a direct impact on their business profitability. They tend to be early adopters of new technologies, which then filter down to non-commercial consumers. Also, heavy trucks, almost by definition, consume a large portion of our energy. This consumption is skewed to the first few years of vehicle service, the period where the products are placed in heaviest service.

Another person remarked on the integrated approach to optimize engines for BSFC/NO<sub>x</sub>, adding that the overall roadmap was outlined, but no indication was given regarding where the project is on the roadmap itself. Some of the data presented did not look very fuel efficient (i.e. heat balance pie chart).

One final reviewer stated that the means to demonstrate compliance with emissions standards was not clear.

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

The first respondent indicated that Caterpillar's internal organization has the capability to bring the technology to the marketplace if and when appropriate. One reviewer stated that there is a good map forward leveraging a variety of external resources, while another person commented that there is a well balanced approach among metal and optical engine experiments and complementary simulation. This reviewer added that the partnership with ExxonMobil to explore fuels effects is a plus. One person remarked that they should get to waste heat recovery projects quickly, while another highlighted the high EGR %.

To contrast, one reviewer commented that it was not shown that the technological barriers could be overcome, and there was an insufficient quantification of improvements. Another reviewer agreed, stating that he or she was not sure if the goals are achievable technically - lots of "info" presented - but this reviewer didn't see any clear identification of where the target is and how close they are to achieving it. Heat balance brake power (thermal efficiency) does not look good. Why is this group taking a fuels approach? It is OK to check, but it makes deployment much harder. No info on fuels offered - is it practical? CAT didn't offer any information here, and there was no indication that the technical barriers are being overcome or that progress is being made.



## 2008 Annual Merit Review

### DOE EERE Vehicle Technologies Program

One final reviewer indicated that achieving 0.2g/bhp-hr NO<sub>x</sub> without NO<sub>x</sub> A/T and 55% BTE seems unlikely. Gains in efficiency are assumed by getting rid of NO<sub>x</sub> A/T. However, it is unclear how HECC will enable thermal efficiency to be maintained throughout the engine map, especially at full load. It would also be useful to understand what the tradeoffs are and what will need to happen to achieve the elimination of NO<sub>x</sub> A/T, such as fuel changes. Is the approach to meet 2010 emissions without NO<sub>x</sub> A/T compatible, or with NO<sub>x</sub> A/T that will most likely be required to meet future emissions standards?

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

One reviewer commented that progress is being made in increasing efficiency, while another noted the good results on the effects of fuel cetane on improving the power of HCCI. One other individual indicated that the advanced engine will most likely require operation in a mixed HCCI/conventional diesel mode. The work should be directed into controlling transitions, transients, and associated controls, particularly if the engine will employ two-stage boosting systems.

To contrast, one reviewer stated that a lot of work seems to have been done but is not reflected in the presentation. Another added that it was not shown that the technological barriers could be overcome, and there is an insufficient quantification of improvements. One person was not sure if the goals are achievable technically – there was lots of "info" presented but this reviewer didn't see any clear identification of where the target is and how close they are to achieving it. One final reviewer stated that gasoline blending is probably required for HCCI. This reviewer doesn't see a special fuel as being practical, at least for early introduction.

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

The first reviewer stated that an engine manufacturer is leading the project, ensuring a path to deployment. One person noted the good collaboration with Sandia, Exxon/Mobil, and IAV, while another added that Caterpillar is an OEM, so technology transfer can occur quickly.

One reviewer indicated that HCCI still has fundamental issues with stability and noise which must be overcome to bring the concept to production. This reviewer doesn't see a direct path to production, even on a limited scale, except at part load as discussed. This is a change from previous CAT presentations.

Another respondent stated that, without seeing technical status towards objectives, it is hard to imagine this work will be transferred to achieve DOE goals. If results are promising, CAT could be in a good position to implement except if it requires fuel changes, for example. One response indicated that, although it may not deliver as much efficiency as promised, the understanding gained will improve HD diesel efficiency. Dual fuel solutions are generally unacceptable to customers, and mixing gasoline and diesel in a gas tank is explosive. One final reviewer felt that very little information was shared on how the fuel was blended. It would be good to know the grades of commercial fuel, bulk property range tested, how they impact engine performance, etc. This would be interesting to hear about next year.

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

One reviewer stated that the funding was appropriate given the scope.



Others disagreed, with one response stated that the level of funding appears extremely high. Similarly, one reviewer began by asking if this project includes the Sandia activity. Historical program results from a few years ago have shown good technical insights and development strategies – but this reviewer didn't see the same quality of R&D here. This project seems to have too many resources considering the lack of deliverables/data/results. One final reviewer added that, although he or she can appreciate the good work shown and the accomplishments to date, this reviewer expected more progress with the given high funding level. Also, it was not clear how the work at Sandia was supported. Did it come from Caterpillar's DOE funds or was it funded directly from DOE to Sandia as a part of their own LTC programs?

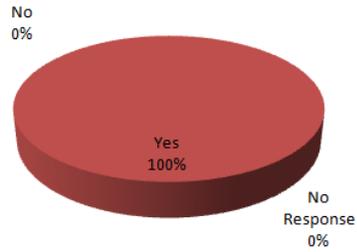
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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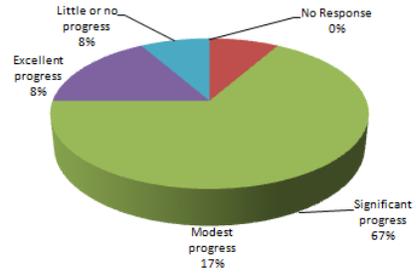


**Project:** Development of Enabling Technologies for High- Efficiency, Low-Emissions HCCI Engines

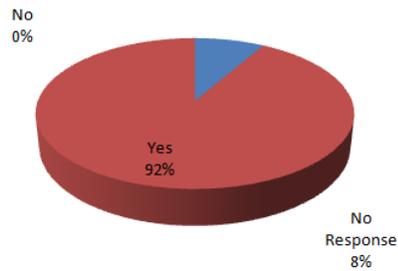
**Question 1:** Does this project support the overall DOE objectives of petroleum displacement?



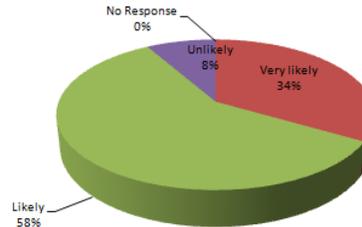
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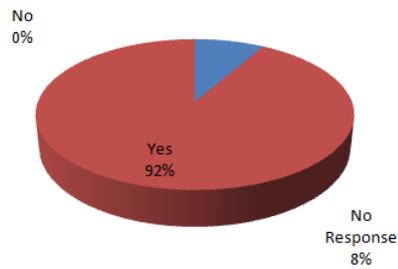
**Question 2a:** Are the goals of the project technically achievable?



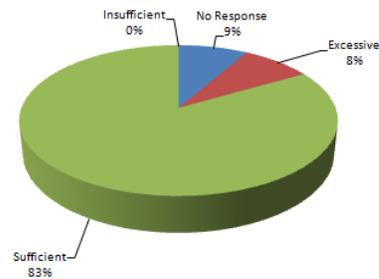
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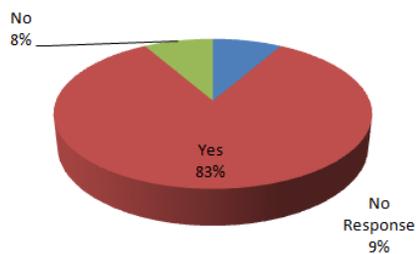
**Question 2b:** Have the technical barriers been identified and addressed?



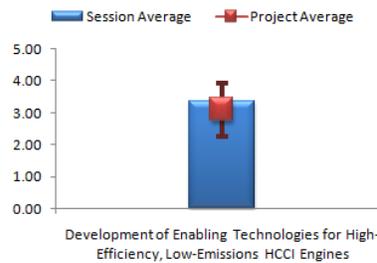
**Question 5:** Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



**Question 6: Overall Rating**



**Enabling High-Efficiency Clean Combustion (HECC) (Don Stanton, of Cummins Inc.)****Reviewer Sample Size**

This project had a total of 14 reviewers.

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

Multiple reviewers commented on the improved efficiency possibilities, with one reviewer stating that the project aims at improving heavy-duty diesel engine efficiency. Another wrote that the project is well-aligned with DOE's objectives to improve the fuel economy of both heavy-duty and light-duty engines, while satisfying 2010 emissions standards. One reviewer indicated that the efficiency goals are realistic and achievable, and will result in measurable improvements in light- and heavy-duty diesel fuel efficiency. Another said absolutely yes – both the light and heavy-duty projects are directly and intimately focused on reducing both engine-level and vehicle fuel consumption. This is a very good program.

One individual noted that the goal is to improve BTE of engine, while another added that a 10% BTE improvement at 2010 emissions levels meets the program objectives. One other person commented that the aim is to help efficiency in HD, but the project is not actually targeting 55% peak thermal efficiency.

One final reviewer stated that this is a good approach to heavy-duty vehicles, and medium-duty engines are being looked at. There are good interim results claimed – it is reasonable that ISX steady-state results are achieved, but the FTP transient is problematic. There is, however, no information regarding how the results are obtained.

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

Three reviewers stated that this is a well thought-out plan for development and demonstration, while another reviewer commented that the project involves the integration of many subsystems and components.

One person stated that the commercial viability aspects were positive – this reviewer likes that OBD is considered during the R&D phase - but he or she trusts only very advanced OBD approaches to the new DOE sponsored technologies would be examined. OBD development is a normal development requirement for certification and general OBD development may not be appropriate for this DOE program.

Another person commented that the PI fully understands the engine- and vehicle-level challenges associated with reducing engine-out NO<sub>x</sub> while meeting the targeted 55% brake thermal efficiency. One potential barrier that should be carefully addressed is the impact of the additional cooling requirements on vehicle-level fuel economy. The work to date does not appear to have addressed this matter in detail. One concern is that the steps taken to improve the current brake thermal efficiency may result in little if any (and hopefully not a decrease) improvement in vehicle level fuel economy. It would be helpful to understand all of the associated parasitic loads associated with increased air flow (charge air cooling) and higher EGR rates (another high cooling load).

One reviewer asked whether NO<sub>x</sub> aftertreatment is required to meet emissions restrictions. Adding to this, one other individual stated that achieving 0.2g/bhp-hr NO<sub>x</sub> without NO<sub>x</sub> A/T and 55% BTE is challenging. The group is assuming large gains in efficiency from getting rid of NO<sub>x</sub> A/T; however, it



is unclear how LTC will enable thermal efficiency throughout the engine map, especially at higher loads. It would be useful to understand what the tradeoffs are to achieving the elimination of NOx A/T and whether it is possible with various fuels. Is the approach to meet 2010 emissions without NOx A/T compatible, or with NOx A/T that will most likely be required to meet future emissions standards?

One response indicated that it was not shown that the technological barriers could be overcome, and there was an insufficient quantification of improvements. Another person commented that the presenter presents some general ideas in improving BTE, adding that maybe that is the way to reach the target. One final reviewer remarked that the selection of the material that was presented made it difficult to assess the modeling and diagnostics that have been used to support engine development.

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

Four reviewers stated that there was good or reasonable progress over last year, with one adding that exploring the expansion ratio path is good for the HD applications. Another reviewer added that the group is accomplishing regular milestones in overcoming technical barriers. Transient control and calibration will be one of the keys to meeting the stretch goals going from optimized steady operation to transient vehicle-like operation. One other person noted lifted flame diffusion control technology will be an interesting research area.

One individual commented that, to date, this project has shown a potential roadmap for meeting 2010 standards while considerably improving today's state-of-the-art engine peak thermal efficiency for both medium and heavy-duty sectors. As pointed out above, more vehicle level systems integration work needs to be performed to assess the real world impact on composite vehicle fuel economy. Another reviewer added that the project appears to have made considerable progress toward overcoming barriers. However, very few technical results were presented, thus reducing the impact that the project can have on the technical community. This reviewer finds quite unacceptable that the technical graphs were presented without having figures on the axes. This way it is impossible to assess, for instance, fuel economy and emissions trade-offs.

One reviewer stated that they would like to see more results, while another added that it was not shown that the technological barriers could be overcome, and there was an insufficient quantification of improvements. Another person stated that the group claimed that the results are impressive - but no info is presented on how the results are achieved. One final reviewer indicated that no detailed information was presented, for example, BTE or BSFC. And the approach of how to reach the 2010 emissions target is unclear.

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

The first reviewer commented that some parts are likely to be commercialized, adding that the lift of technology is feasible with right FIE system, but the three-mode combustion is difficult to optimize. Another reviewer indicated that portions of this effort are likely to transition to the marketplace, such as electric assist turbocharging, variable valve timing, and two-stage turbocharging. Other portions of this effort may or may not find their way into production.

One person noted that a manufacturer leads the project, thus providing a direct path to deployment, while another reviewer stated that Cummins has a good track record of commercialization of its DOE-funded research and development. One individual felt that Cummins is in a good position to integrate



the results into the ISX and ISB - that is assuming that the approaches used are viable. No information was presented on what the actual approach being pursued is. One reviewer wrote that, although OEMs don't appear to be involved much in this program at this time, Cummins is well positioned to bring them in and bring these technologies to market if/when it becomes appropriate. In slight contrast, another reviewer indicated that Cummins is an OEM and will be able to introduce technologies into the market relatively easily.

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

One reviewer stated that the budget looks well-matched to the tasks required, while another person commented that this is a nice program with sufficient resources to address the 55% peak thermal efficiency target for both light- and heavy-duty sectors. One other respondent stated that the resources appear appropriate for the type of work done. However, since details on the approaches used were not given, it makes it difficult to be conclusive about this issue.

One reviewer commented that Cummins does a fine job of leveraging funding for product development activities. Another suggested that the presenters could highlight how the national labs were leveraged in these results.

One final reviewer stated that they would have expected to see more accomplishments for the given funding level this year.

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

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

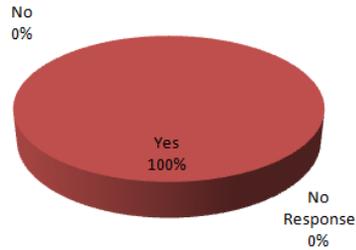


# 2008 Annual Merit Review

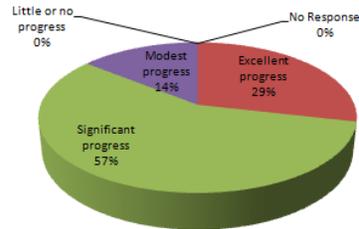
## DOE EERE Vehicle Technologies Program

**Project:** Enabling High-Efficiency Clean Combustion (HECC)

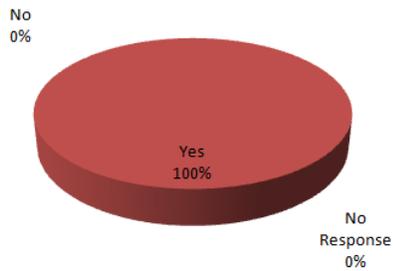
**Question 1:** Does this project support the overall DOE objectives of petroleum displacement?



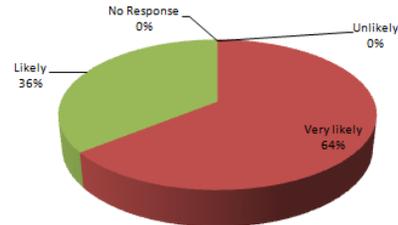
**Question 3:** Characterize the technical accomplishments and progress toward goals.



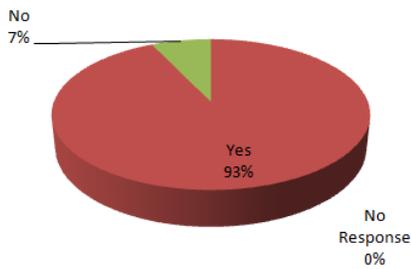
**Question 2a:** Are the goals of the project technically achievable?



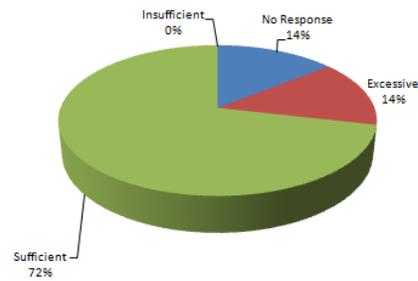
**Question 4:** How likely is the project team to move technologies into the marketplace?



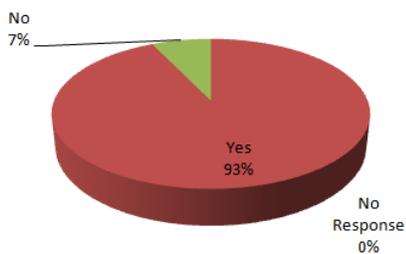
**Question 2b:** Have the technical barriers been identified and addressed?



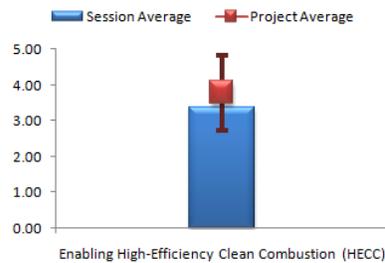
**Question 5:** Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



**Question 6: Overall Rating**



## Engine System Approach to Exhaust Energy Recovery (Rick Kruiswyk, of Caterpillar Inc.)

### Reviewer Sample Size

This project had a total of 7 reviewers.

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

Two reviewers stated that the project supports meeting efficiency goals on HD diesel. Another person commented that it aims at achieving 10% efficiency gains via exhaust waste-heat recovery for heavy-duty trucks, a reasonable goal. One other reviewer said there is a very clearly defined path to reach the 10% goal, in line with DOE objectives.

One final reviewer stated that it seems that CAT is working hard on several fronts to achieve the program goals and therefore DOE objectives. This seems to be a good use of advanced analytical tools and results from other programs. This reviewer is not sure if CAT is in a position to deploy results from the analysis – it seems that a turbocharger partner may be advantageous to the program. For example, if the full turbo system does not work, minor advances may not be adopted into real hardware without a turbocharger partner. Additional barriers exist involved in the details of matching compressor/turbine – classical equations are not sufficient for this. Detailed flow effects and pulsation will have a large influence on the actual testing result.

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

The first reviewer indicated that use of the second-law analysis to identify areas to attack for efficiency improvement lead to an approach is well thought out.

In contrast, one reviewer stated that this appears to be a difficult approach to apply to a series turbocharged engine, while another person added that the barriers for the defined path are significant to get this approach into a deployable solution. One respondent stated that CAT is considering the deployment barriers and applying analytical techniques. It seems that the turbo aerodynamics and the Brayton cycle packaging and heat exchanger packaging barriers would suggest including a turbo partner or a vehicle partner. But the cost barriers and vehicle packaging concerns still remain.

One reviewer commented that delivery of the 2% efficiency from the high pressure turbine will depend on the success of advanced turbocharger concepts, hence this is somewhat risky. Turbo compounding, being sensitive to the particulate filter back pressure, is somewhat risky. The penalty for regeneration of the DPF does not seem to be addressed. One final reviewer noted that the compound turbine is not newly proposed technology, but there still are some barriers to be identified and overcome: (1) TC transient response on engine performance, (2) friction effect, and (3) package and cost.

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

One reviewer commented that plenty of results have been mentioned – but it is not clear that the approach is feasible considering that cost, vehicle packaging, and heat exchanger barriers were not addressed or at least mentioned. Another individual said that the path defined has been falling short of the predictions, but it appears that they are working to find new/alternate paths to reach the goal. One final reviewer noted that the GEN 1 mixed-flow turbine bench test has shown no improvement to baseline. GEN 2 turbine improvement is only predicted by simulation, and falls short of the ultimate target.



## 2008 Annual Merit Review

### *DOE EERE Vehicle Technologies Program*

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

The first respondent noted that Caterpillar is an OEM, and so they can take the design and knowledge to production relatively quickly. Another reviewer stated that, given that the approach has many elements, the project is likely to lead to some areas of efficiency improvement in the marketplace. However, this reviewer added that the Brayton cycle work will only benefit HD and won't transfer to LD.

One reviewer indicated that there are plenty of results mentioned, but it is not clear that the approach is feasible considering that cost, vehicle packaging, and heat exchanger barriers were not addressed or at least mentioned. One final reviewer commented that patents are usually a hindrance to technology transfer, not an enabler. The likelihood of this complete system technology making it into the marketplace is probably not good. However, he or she can see some aspects (i.e. the turbocharger work) of this being very viable.

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

The lone respondent stated that the accomplishments seem to be appropriate for the funding level of this project.

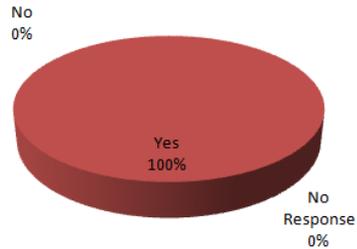
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

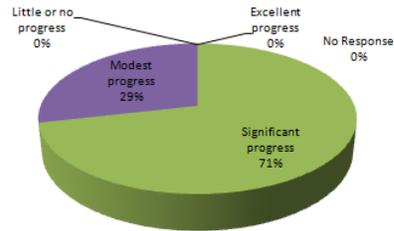


Project: Engine System Approach to Exhaust Energy Recovery

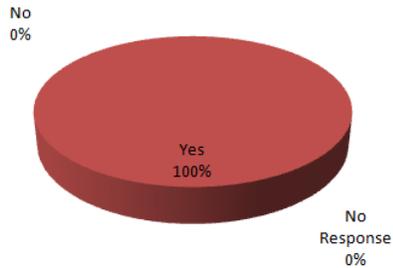
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



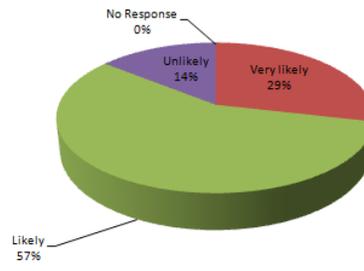
Question 3: Characterize the technical accomplishments and progress toward goals.



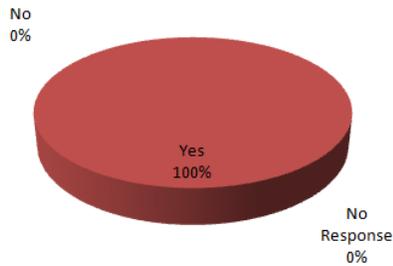
Question 2a: Are the goals of the project technically achievable?



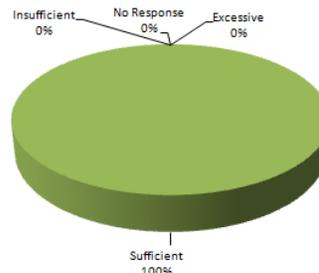
Question 4: How likely is the project team to move technologies into the marketplace?



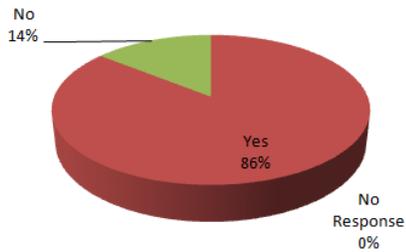
Question 2b: Have the technical barriers been identified and addressed?



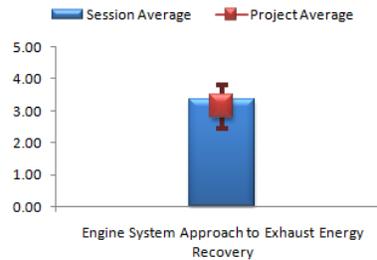
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



Question 6: Overall Rating



### Exhaust Energy Recovery (Chris Nelson, of Cummins Inc.)

#### Reviewer Sample Size

This project had a total of 8 reviewers.

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

One reviewer stated that the 10% overall improvement in efficiency meets the DOE objectives, while another stated that 10% efficiency improvement is anticipated for waste heat recovery, which is reasonable. Very similarly, one person commented that using waste heat recovery system can improve engine efficiency. One other respondent stated that the 10% technical improvement claimed is large. The cost requirement is also high, so this is a high risk/10% reward project.

One reviewer remarked that waste energy recovery will be an integral part of future high efficiency engines. WHR may be an important component of this (although lower hanging fruit like turbocompounding is here already). One final reviewer stated that improving efficiency through waste heat recovery is only applicable to heavy-duty vehicles.

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

The first reviewer stated there is a good test plan in place, while another added that there is good analysis that will lead to decision making. This is a good approach to have go-no-go decisions in each phase and to prove out the concept analytically. One other reviewer complimented the idea to capture the EGR cooler heat rejection and use it for waste heat recovery – this is an advance over "historical" Rankine bottoming cycle ideas. It seems that intelligent compromises have been made to optimize the initial system prior to the start of development – this is important for deployment. Cost and additional complexity are probably the key barriers, and this reviewer did not see any new concepts to overcome these.

One reviewer wrote that HD application is only for the Rankine cycle due to the need for high quality exhaust for recovery. The expense of the system would probably be prohibitive for light-duty applications. Packaging has been addressed quite extensively. Another response stated that using the Rankine cycle is a good approach but needs to be demonstrated. One final reviewer noted that some results indicate the approach is feasible but cost and weight need be fully considered if the system should be used in light-duty vehicles.

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

One reviewer stated there is very good progress shown in all areas of this system, while another complimented that detailed design, adding that it is good to start with the vehicle application up front and concept design integration into the vehicle. It is good to see a lot of work up front on the Cyber Vehicle to plan out the available power/benefits.

One person noted that the schedule has slipped – no real reasons provided, but re-scheduled list of tasks seems reasonable. Another person stated that it is hard to be confident about this remark, but judging from the cumulative amount of work "completed" for Phase I and II (from pre-2005 to the end of 2007), the progress seems relatively slow.



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

The first respondent noted that Cummins is an OEM, and that all the work to demonstrate the concept is being done on prototype hardware on near-production engines. Another person commented that there are good collaboration with and relevant partners in Cummins/ITEC – integration to a low emission engine is an advantage over historical designs. One important issue is the strategy to overcome the implementation cost barrier. It is hard to imagine implementing a limited scope concept of this technology as a market transformation – so this reviewer believes the likelihood is low, although he or she does think the presentation/planning was good.

One response stated that it will be a brave company that commercializes this technology, but the first company that does so will not be the last. Another reviewer wrote that the analyses indicate that this will pay for itself in a couple of years; however, cost is likely to prevent implementation for some time.

One person remarked that the group is working with other companies on pumps and controllers for the Rankine cycle waster head recovery. The approach will have difficulty overcoming the negative cost and added weight aspects. This reviewer believes these constraints will likely keep this system from use in transportation applications. One final reviewer also indicated that the complexity of the system and its cost may prevent the technology from being applied into market. If these problems can be solved, it is possible that the system can be used in HD high power required vehicles.

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

One reviewer stated that the support of Cummins seems to be generous in this and related projects, while another person added that \$1.5 million seems high compared to the other projects in this Enabling Technologies category/session. Similarly, one final reviewed added that, although the progress was impressive, this project seems to be funded at a disproportionately high level compared with the others presented.

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

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

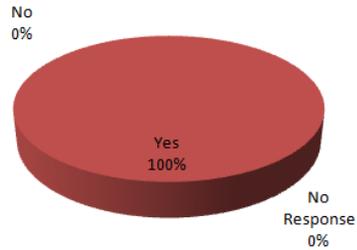


# 2008 Annual Merit Review

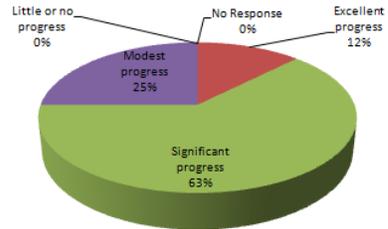
## DOE EERE Vehicle Technologies Program

Project: Exhaust Energy Recovery

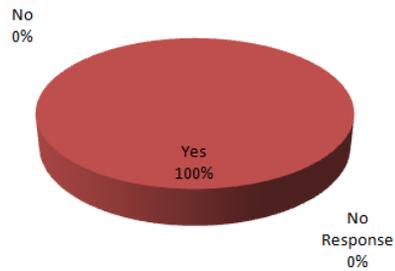
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



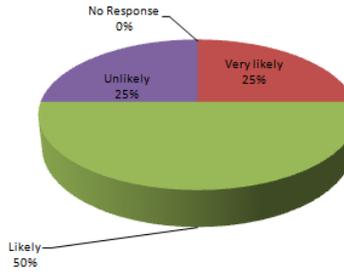
Question 3: Characterize the technical accomplishments and progress toward goals.



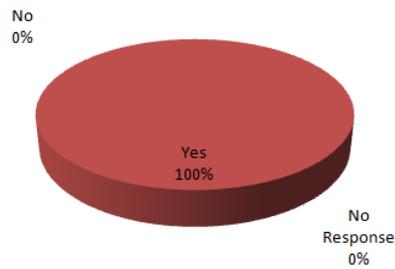
Question 2a: Are the goals of the project technically achievable?



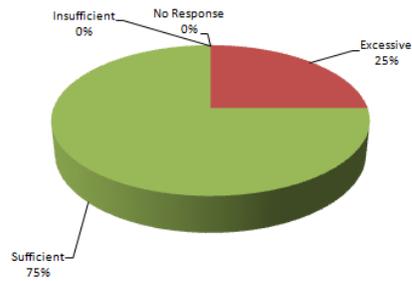
Question 4: How likely is the project team to move technologies into the marketplace?



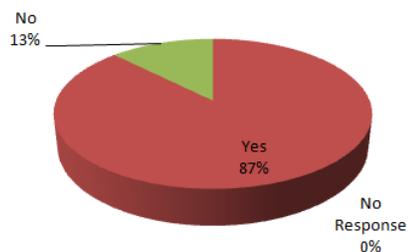
Question 2b: Have the technical barriers been identified and addressed?



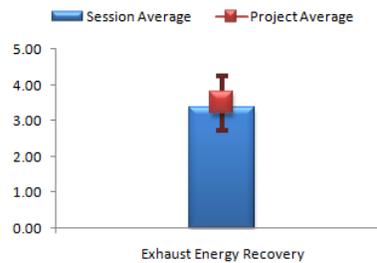
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



Question 6: Overall Rating



## Heavy Truck Engine Development and HECC (Houshun Zhang, of Detroit Diesel Corporation)

### Reviewer Sample Size

This project had a total of 12 reviewers.

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

Many reviewers commented on the efficiency improvement goals for HD diesel, with one reviewer adding that the project aims at improving efficiency while minimizing emissions via PCCI combustion. One reviewer stated that the project is well aligned with DOE's goals of reducing fuel consumption while satisfying 2010 emissions standards. Another person commented that the path toward 55% BTE appears well defined and thus is in line with DOE objectives. One respondent remarked that the evaluation of technology on transient cycle with multi-cylinder engine is a valuable tool.

One final reviewer wrote that it was refreshing that the strategy (urea SCR + turbo compound) and actual BSFC data/targets are shown. This reviewer added that it is good to clarify R&D project targets as well as production impact (45% in 2013); this is a big improvement over the previous two presentations.

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

The first respondent stated that the dual spray-angle injector is exciting, while another person added that it was not shown that the technological barriers could be overcome, but the Delphi FIE system seems promising.

A number of respondents offered suggestions. One person commented that there is a good balance between engine experiments and simulation methodologies. Some complementary optical diagnostics work would be desirable to shed light into performance of variable geometry injection system. Another reviewer remarked that it was impressive that combustion alone is close to achieving goals. This reviewer appreciates the quantitative data of the impacts at A25, A50, B100, etc. How realistic is the variable nozzle technology? Since it is employed over the transient FTP, it seems OK for R&D, but how about production? One other reviewer wrote that the project is only analytically done. There should be some data showing model validation because what the data presented seems too good to be true. What is the true source of the BSFC and emissions reduction?

One respondent felt that this is difficult to assess since so much depends on the proprietary fuel injection strategy. Is this a production viable technology, or only a lab scale demonstration? Another reviewer suggested that the investigators may want to elaborate more on how the efficiency targets are to be met. One final reviewer stated that no detail was shown on how simulation is used to help direct investigations and no fundamental analysis why dual-mode combustion strategy can improve combustion efficiency.

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

One reviewer stated that the project scope and organization is impressive. Many tools like CFD and design-of-experiments are being used in this project. Another commented that clear quantitative targets were shown, and the quantitative results provided show results that are in line with previous targets. It is encouraging that the results already show NO<sub>x</sub> and BSFC improvements in FTP transient



## 2008 Annual Merit Review

### DOE EERE Vehicle Technologies Program

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work. This reviewer looks forward to seeing if the same approach can be achieved with HECC over FTP.

One person remarked that the new fuel injection hardware with variable geometry is on its way. It could play a significant role towards the success of the project under dual combustion modes. The lack of detail provided about the hardware configurations and the intended strategies makes it difficult to assess its benefits at this time. More emphasis on controls of transients and mode transitions is highly desirable.

Adding to this, another reviewer commented that there was a significant amount of analytical data shown giving great results, but the models need to be validated. Nothing was shown indicating that the variable nozzle mechanism is on its way to being developed. Hardware demonstration is necessary to both prove the concept and to validate the models. Similarly, one person wrote that the reported numbers for efficiency improvements are quite impressive. However, this enthusiasm must be somewhat tempered until more can be revealed about the "novel" fuel injection strategy that leads to such dramatic improvements. This reviewer looks forward to DDC revealing that information next year when they have their IP issues resolved. One final reviewer stated that some interesting results were shown but the unreliability of a dual injection system and stability of the injection system have not been validated (this technology was used 20 years ago).

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

The first response stated that the Delphi FIE system has great potential, while another person noted that a manufacturer leads the project, thus providing a direct path towards technology deployment. One reviewer indicated that DDC has sufficient resources to bring these technologies to the marketplace if/when appropriate. One other person stated DDC should be in a good position to implement into the marketplace, and it is encouraging that the program has goals for R&D as well as the production engine implementation.

One reviewer stated that the likelihood of deployed depends on if the injection system reliability can be improved in the future and the control system can work well. Another person felt that the injector's likelihood of success was unknown, and that this area of explanation needs to be expanded. One final reviewer stated that it is unclear whether the variable nozzle concept being assumed for this project can be manufactured.

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

One reviewer stated that the current resources are appropriate for the goals of the investigation, while another remarked there was good progress with the funding provided.

On the other hand, one final respondent indicated that, for the level of funding received, he or she would have expected more than analytical results.

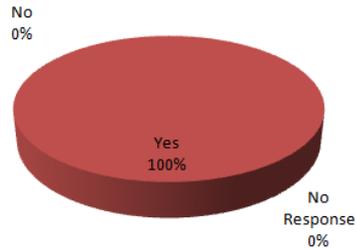
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

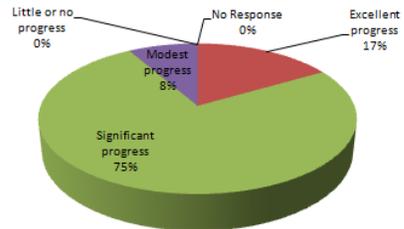


Project: Heavy Truck Engine Development and HECC

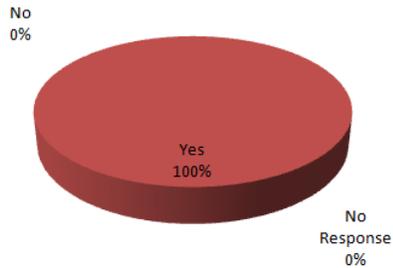
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



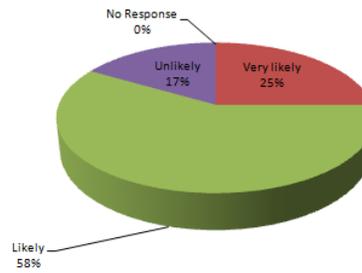
Question 3: Characterize the technical accomplishments and progress toward goals.



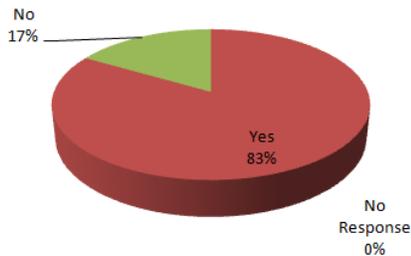
Question 2a: Are the goals of the project technically achievable?



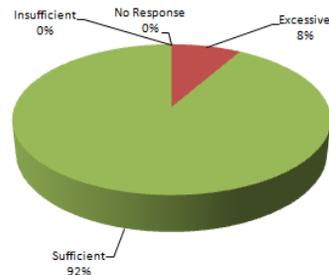
Question 4: How likely is the project team to move technologies into the marketplace?



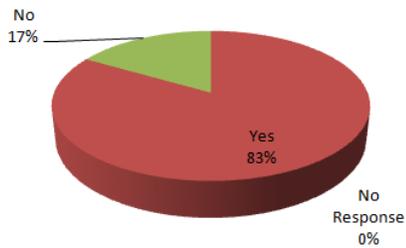
Question 2b: Have the technical barriers been identified and addressed?



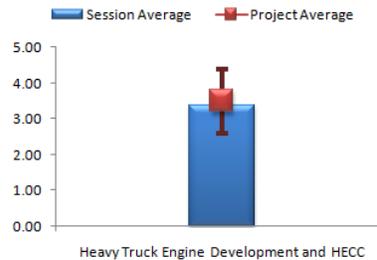
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



Question 6: Overall Rating



### HECC Engine Designs for Spark-Ignition and Compression-Ignition Engines (Ken Patton, of General Motors Corporation)

#### **Reviewer Sample Size**

This project had a total of 13 reviewers.

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

One reviewer commented that the group is working on hardware development to enable LTC and HCCI for diesel and gasoline, while another person stated that the goal to improve engine efficiency at constant emissions level is in line with DOE objectives. One reviewer added that the project supports well the DOE objectives of developing hardware for LTC engine designs that support DOE's objectives to improve fuel economy while satisfying Tier 2 Bin 5 emissions. Another individual remarked that gasoline HCCI is potentially an important fuel reduction technology, as well as the diesel HCCI work performed here. One person noted the 2.2L engine demo car was done in 2007.

One final reviewer noted that HCCI in the vehicle has high potential, although it is not clear what the quantitative objectives are. This reviewer asks, can DOE have each program adopt quantitative targets and present these numbers?

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

The first reviewer commented on the plain good engineering of the project, while another reviewer stated that the project harnesses HCCI R&D efforts internal to GM, as well as those available through the scientific community. It applies the knowledge and understanding to development and packaging of components and sensors required for an actual product. There appear to be good synergies between the gasoline and diesel foci of the project. One other person stated that the two-stage and VVA are the most effective ways to improve BSFC.

One reviewer noted that the program is a little different than others in that it is a design exercise and specifically directed at gasoline engines. Another individual felt that the strategy for deployment was difficult to assess. The in-cylinder pressure sensing on the LD program shows a good opportunity for deployment on either LD or HD engines, but this reviewer does find the admitted lack of interaction between the LD and HD programs at GM a bit disturbing.

One response felt that GM's goals in the project were not clear, while another reviewer indicated that GM has shown a willingness to deploy their advanced technologies in practice, as well as a good sense of realism in their project goals and assessments of potential pitfalls and barriers.

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

One reviewer commented that there is a realistic approach, while another person noted the good, steady progress in this project (on both the diesel and gasoline fronts). One response stated that the LIVC work on the HD program is showing good progress. This reviewer would like to see this continued. Another person stated that the project has already demonstrated the benefits of implementing fully flexible and production-intended VVA systems (alongside the associated HCCI control and transition strategies) in a vehicle. One other reviewer remarked that a lot of the issues with technology commercialization (e.g., camless and cylinder pressure sensors) have been well understood within the industry. This program seems to be set up to address those issues.



One reviewer noted that a 2.2L demo car was presented in 2007, adding that the VVA system may have system stability problems based on the schematic diagram presented. One final reviewer commented that the vehicle demonstration of HCCI seems impressive – but what is the emission level? Is this consideration part of the DOE program?

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

The first respondent indicated that there is a realistic approach, while another reviewer stated that this project has an excellent path towards demonstration, deployment and commercialization. It is an exemplar of transition from basic R&D (GM internal and leveraged from academia such as the GM-CRLs) to development of hardware components and their integration into product deployment. The project will also provide an excellent assessment of HCCI enabling technologies and sensors.

One person remarked that technology transfer must also include the transfer of information from the company to the rest of the (interested) world, such as academic institutions – and not just within GM. Another reviewer added that the presentations did not cover anything other than internal GM interactions (although not between LD and HD!). One SAE publication on the LIVC portion is good to see for some technology transfer. One final reviewer stated that it is not clear that the approaches being looked at are viable – there is no transient control of VVA.

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

One reviewer stated that the resources are appropriate for the project's objectives, while another person added that there is a good use of DOE funding to leverage company resources. One respondent added that GM has the technical potential to support the project (based on what was stated in the presentation).

One reviewer indicated that this looks like this is a supporting program. One person asked about how the university and labs were utilized in this project.

Another response indicated that the level of funding seems low to be spread out over two separate programs for gasoline and diesel. One final reviewer stated the FY08 funding looks small relative to other projects. Does this have carryover from previous years?

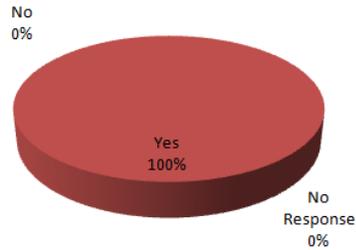
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

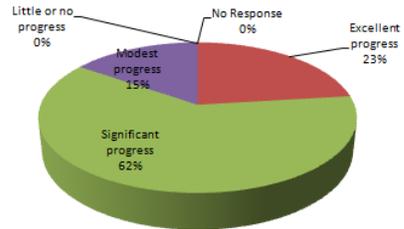


**Project:** HECC Engine Designs for Spark-Ignition and Compression-Ignition Engines

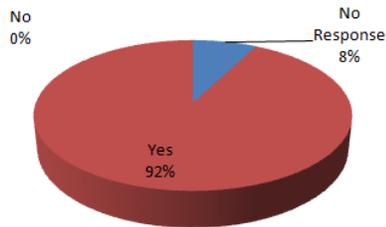
*Question 1: Does this project support the overall DOE objectives of petroleum displacement?*



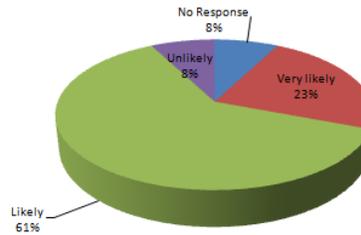
*Question 3: Characterize the technical accomplishments and progress toward goals.*



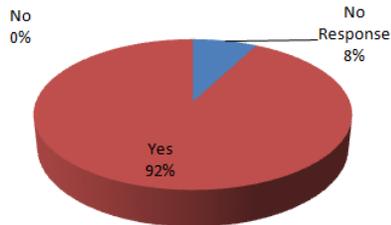
*Question 2a: Are the goals of the project technically achievable?*



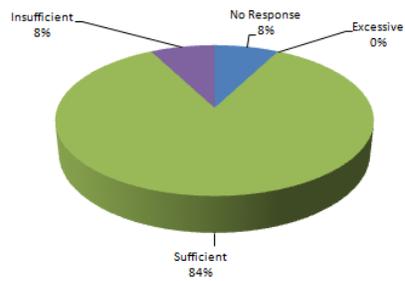
*Question 4: How likely is the project team to move technologies into the marketplace?*



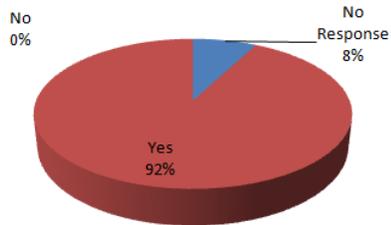
*Question 2b: Have the technical barriers been identified and addressed?*



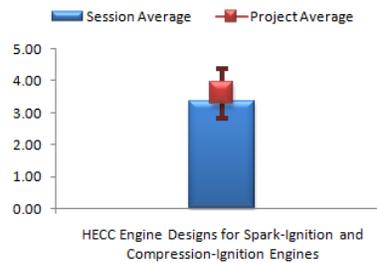
*Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.*



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



*Question 6: Overall Rating*



## Light-Duty Efficient Clean Combustion (Tim Frazier, of Cummins Inc.)

### Reviewer Sample Size

This project had a total of 10 reviewers.

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

Responses were generally positive to this prompt, with multiple reviewers commenting that the goal of 10.5% improvement in diesel engine thermal efficiency is in line with DOE objectives and will help to reduce future fuel consumption in the US. One of these reviewers added that the evaluation of biodiesel's impact is important to help make it clear what the introduction of biofuels will mean. Another person stated that, if achieved, it will support the DOE objectives. One other response indicated absolutely yes. This is a very aggressive program that attacks current fuel efficiency penalties associated with meeting future emission standards, and also will look at extending fuel efficiency beyond the penalties imposed by emissions compliance on today's engines.

One reviewer commented that this project is a light-duty diesel enabler – 10% improved city fuel economy (FTP-75) is a key step. This is a multi-pronged technical approach to expand the state of the art. There should be good synergy with the HECC program (high load emphasis) and this program (low load emphasis project) – all programs have good emphasis on controls. One final reviewer stated that many aspects of state-of-the-art HECC technology are being brought to bear on the project.

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

Multiple reviewers commented that there is a good, thorough plan for project progression. One reviewer added that the project has many items that will be examined, all of which appear reasonable to pursue for light-duty diesel. Another added that there are no results as of yet, since the project just started up, but noted that the fuel sensing capability is a good element of the program. One other reviewer stated that it will be interesting to see how this program progresses.

Similarly, another person indicated that the program has just started – there is only a plan, with no results so far. It seems to have a detailed multi-pronged approach to achieving the goals, and there should be good synergy with the HECC program (high load emphasis) and this program (low load emphasis project) – all of these programs have a good emphasis on controls. One individual stated that the proposed technologies and components to enable meeting fuel economy and emissions deliverables are right on target, and it shows good knowledge of state-of-the-art. He or she is looking forward to see what they can achieve.

To contrast, one reviewer commented that this is a very aggressive project and it will be difficult to attain the 10% peak thermal efficiency improvement. The combination of NO<sub>x</sub> aftertreatment elimination and advanced wide range turbocharging will improve upon peak thermal efficiency of today's diesel engines. To meet the 10% goal, the contractor will have to meet or exceed efficiency improvement targets in the controls area, LTC area, and air handling system while considering final vehicle integration – this will be difficult. One final reviewer added that fuel injection systems, air handling system, and controls and sensing system of the engine are the current technologies to improve BTE. The last one will be challenging and hard to realize in a production engine.



## 2008 Annual Merit Review

### *DOE EERE Vehicle Technologies Program*

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

Most of the reviewers indicated that the program has not really gotten started yet or is a new project. One person stated that this is still in the analysis stage, while another noted the previous questions were not applicable, as this is a new project. Another reviewer remarked that this project is just getting started, and hence the low scores should be disregarded. The proposed plan is impressive, almost too optimistic – e.g. the hope of eliminating the NO<sub>x</sub> aftertreatment system (especially with turbocharger). This reviewer added that solving the air-plus-EGR handling system may not be done easily.

One final reviewer also stated that the project is in its initial stages. Elimination of NO<sub>x</sub> aftertreatment is a worthy goal, but needs to be better motivated, as this represents a large portion of the fuel efficiency improvement gain that the researchers anticipate.

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

The first reviewer indicated that achievements have a clear path to commercialization for light-duty diesel. One respondent noted that Cummins has a good track record of commercialization, but this project is still in its early days as of yet. Another reviewer added that Chrysler is the partner of Cummins, and the engine developed will be applied in a Chrysler vehicle. Similarly, one reviewer said that Cummins is an OEM and technology transfer will be natural. Mule engines for this technology development can be easily made into product. One person commented that various portions of the technologies targeted for further development within an engine system are likely to find their way into the marketplace given that the lead company is also the manufacturer of the engine system under consideration. At a minimum, it is anticipated that work in the advanced turbocharging and fuel injection system areas will evolve into future engine products. Another person felt the partnership with Daimler-Chrysler is good for helping move results to the marketplace. Is this relationship the same now under the new Chrysler ownership?

One reviewer commented that this program is planning to utilize a number of modest 'stretch' technologies that should be coming available in the next few years. This reviewer added that this is an ambitious goal to eliminate aftertreatment.

One final reviewer expressed some doubt regarding whether or not eliminating NO<sub>x</sub> aftertreatment is actually viable with US06 requirements and possible LEVIII emissions requirements, even with all of the areas they plan to examine.

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

One reviewer commented that there is good leveraging of DOE funding with industry contribution. Another stated that resources seem to be consistent with HECC program – so there seems to be enough funding and supporting programs available to support this work. One individual remarked that, according to the presentation, it appears that the contractor has adequate overall engineering and financial resources to efficiently address program goals.

To contrast, one respondent stated that the work plan for FY08 looks a little aggressive for the moderate funding level in the first year. Another commented that there are no visible links to other labs/universities, etc. One final reviewer indicated that, among the technologies mentioned, robust combustion control will be challenging to realize within the expected time period.



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

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

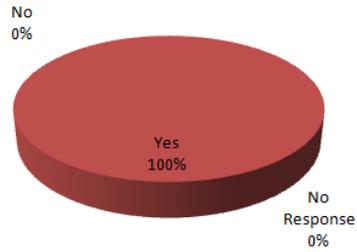


# 2008 Annual Merit Review

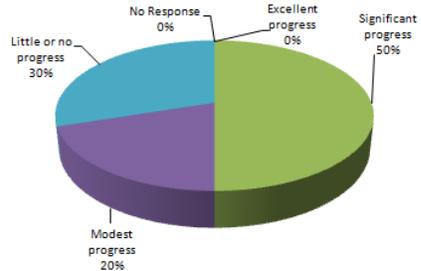
## DOE EERE Vehicle Technologies Program

Project: Light-Duty Efficient Clean Combustion

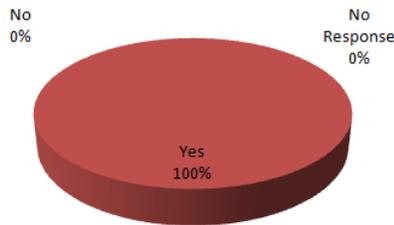
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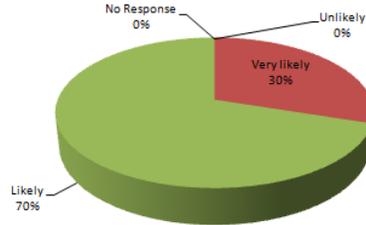
Question 3: Characterize the technical accomplishments and progress toward goals.



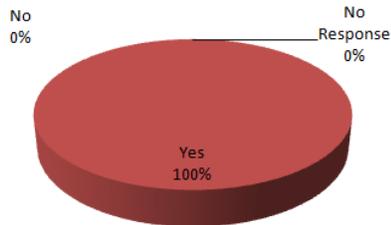
Question 2a: Are the goals of the project technically achievable?



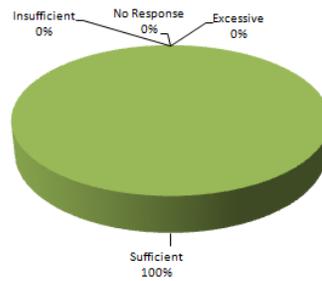
Question 4: How likely is the project team to move technologies into the marketplace?



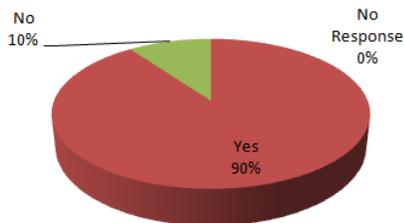
Question 2b: Have the technical barriers been identified and addressed?



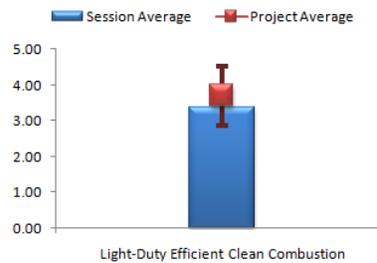
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



Question 6: Overall Rating



## Low-Cost, Fast Response Actuator (Charles Mendler, of Envera LLC)

### Reviewer Sample Size

This project had a total of 13 reviewers.

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

One reviewer commented that there is a high efficiency improvement potential, while one person commented that this is an enabling technology to support HCCI. Another reviewer indicated that the variable compression ratio has a high potential for fuel efficiency. One individual stated that VCR is supposed to improve engine BTE, while another response said that VCR engine operation is an important potential enabler for both fuel efficiency improvement and for the use of alternative fuels such as higher efficiency octane bio-derived fuels. One other reviewer stated that variable compression ratio hardware that is practical and affordable would make a significant contribution to supporting DOE's fuel economy goals.

To contrast, another reviewer stated that the benefits were indirect. VCR does have benefits for new combustion regimes, but they may not yet be fully developed yet. One other reviewer added that a cost benefit analysis is needed before value can be assessed. One final reviewer remarked that it seems that no one knows if there are any benefits. This VCR concept should be modeled as part of the engine system – cycle-simulation modeling should show the projected benefits first over steady state, and then over a transient excursion. All VCR methods are not created equal, and this reviewer asks what the system technical capabilities are to modify VCR over the engine transient. This reviewer thinks it is good for DOE to invest in a distributed portfolio with high risk/high reward concepts included to some extent – however, high risk projects should be fully evaluated to understand the technical objectives and benefits before building hardware.

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

The first reviewer stated that the project goals seem reasonable and feasible. Good luck. Another respondent commented that VCR has been demonstrated as a viable tool for advanced combustion. This reviewer would like to see several more competitive concepts like this funded.

One person stated that this is an interesting development of the FEV technology, adding that the movement of the crankshaft and coupling to transmission was not addressed. Another reviewer commented that the objective seems to be to build the system and test it – why not ask a NL or an engine consultant to do some modeling to check this system out? One other respondent stated that the project needs a Ford / GM / Chrysler connection. A project like this needs critical mass or else it is doomed to fail.

Another reviewer stated that full engine testing should address the performance potential of this concept. Similarly, one response indicated the need to demonstrate the ambitious objectives of the new technology in an integrated system. While the hardware is built, its ability to overcome the technical barriers in an integrated fashion has yet to be demonstrated. The project needs to use modeling and simulation tools more to guide hardware development, including multi-body dynamic system simulations. One final reviewer remarked that this concept has a significant number of barriers to clear. It is likely that many of these have probably not even been identified yet until a hardware demonstration has been built and tested.



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

Responses were generally mixed for this prompt. One reviewer commented on the clever development of the FEV technology with hydraulics and offloaded endpoints, adding that the efficiency potential of 30 % is realistic. Another stated there has been good progress on this project.

One person commented that all of the devices aimed at providing VCR capability are complex and subject to variability / tolerance stack ups, strength and wear, but if successful are enablers for HCCI. This is a good example of high risk and high potential payoff technology. Another reviewer noted that the emphasis looked like it focused on CAD, with no testing – FMEA type work shown. Another person reviewer suggested the technology needs an OEM to prove its ability to reduce fuel consumption.

One respondent felt that it is difficult to assess the technical accomplishments based on the very limited information disclosed. The project has developed hardware, but it is hard to assess if it has the potential to meet the project's ambitious goals. One final reviewer stated that, from the presentation, it was difficult to tell which accomplishments were from this last year. This reviewer is not sure this project is making progress at a rate that will overcome the major technical challenges ahead of it in the near future (less than 5 years).

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

Responses were generally negative to this prompt. One reviewer simply commented that he or she has been waiting for someone to advance this technology, while another said that technology transfer will increase the closer to production feasibility this technology comes. One reviewer suggested that Envera needs to work more closely with engine OEMs to enhance the commercialization prospects of the system. There does not appear to be any current interest from US manufacturers. Similarly, one person stated that the lack of any industrial partnerships is going to make this difficult to get into the marketplace, while another felt that, without commitment by an OEM, a project like this does not have a chance to demonstrate its potential. One other person stated the concept is potentially an enabler for HCCI but the hardware needs to be proven on a running engine.

Other reviewers expressed cost / manufacturing concerns. One respondent indicated that, based on currently available data, there is no reason to expect any real advantage. Another person thought that this would take a long time to develop because of the high risk. One reviewer stated that the cost, weight and increased package space will make this technology unattractive. One final reviewer stated that this technology may have applications in niche vehicles, but large market penetration will be difficult.

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

One reviewer stated that there was good leveraging of DOE funds in this project. Another person commented that, although this project is modestly funded, it needs a manufacturer to join in the effort, which looks like it may come from Mercedes in the future. One other reviewer noted the project needs full involvement and commitment from an OEM.

One person felt that not enough information has been presented on the total funding of the project, so it makes any assessment difficult. Generally, the development, control, and demonstration of a practical VCR system require a significant investment. One final reviewer asked if detailed stress analysis has been done on a multicylinder arrangement.



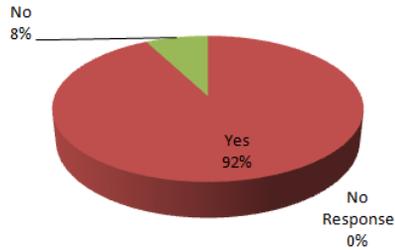
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

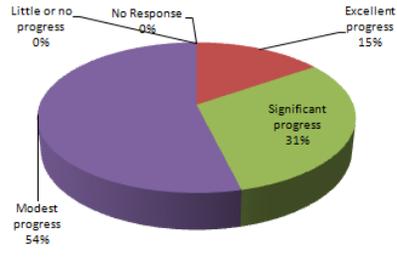


**Project: Low-Cost, Fast Response Actuator**

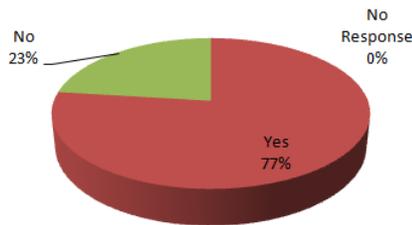
*Question 1: Does this project support the overall DOE objectives of petroleum displacement?*



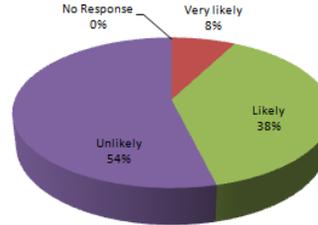
*Question 3: Characterize the technical accomplishments and progress toward goals.*



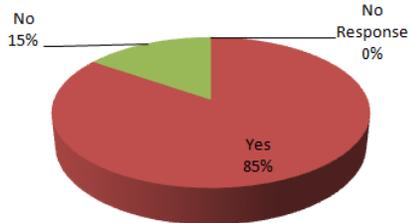
*Question 2a: Are the goals of the project technically achievable?*



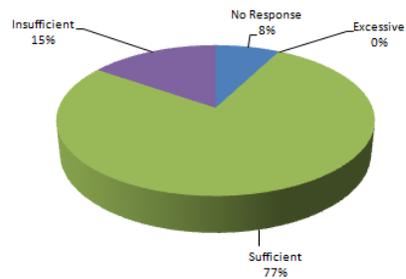
*Question 4: How likely is the project team to move technologies into the marketplace?*



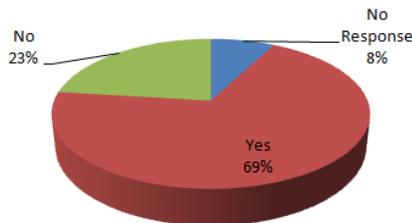
*Question 2b: Have the technical barriers been identified and addressed?*



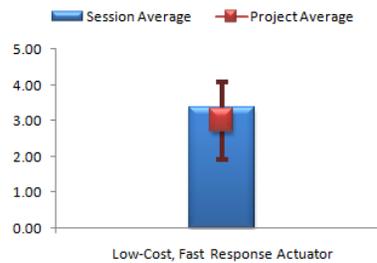
*Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.*



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



*Question 6: Overall Rating*



## Low-Temperature Combustion Demonstrator for High-Efficiency Clean Combustion (Willy Ojeda, of Navistar Inc.)

### Reviewer Sample Size

This project had a total of 10 reviewers.

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

One reviewer highlighted the improved efficiency, while another person indicated that the goal of the project is to improve fuel economy and reduce emissions. One individual commented that this is an extremely low-cost, high-return project that will result in appreciable fuel consumption reductions in next generation engines. Another reviewer remarked that the LTC project supports DOE objectives of improving fuel economy while satisfying emissions constraints.

One response said there is good work on pushing the upward load limit on a medium-duty operating in HECC mode. This project does address DOE's fuel economy improvement goals, but does not appear to be as aggressive as other engine OEMs. This could be based on the fact that the presentation was shortened and this reviewer did not participate last year.

To contrast, one reviewer remarked that there is nothing new being done. This seems like a standard development project – what are the quantitative targets/objectives? One final respondent felt there was not much info presented about the achieved or expected BTE on this program. This reviewer assumes since it is LTC work that it is there, if not explicitly.

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

The first reviewer stated that this is nice application work with a focus on known problems, while another felt that there was a good balance among modeling/simulation and experiments, adding that the involvement of Conoco/Phillips on the fuels side is a plus. One person indicated that the program looks to be on a good path to keep the work production viable, which will enable deployment. Another reviewer stated that the project goals are well established, and technical barriers are laid out. The project team seems to have a good idea of the problems facing them, and the approach is realistic.

One reviewer commented that it is not clear on what the quantitative goals are. The technologies chosen appear to be production viable - new technology is added (in-cylinder pressure sensing and VCR?) but what is the benefit to BSFC? What is the NOx reduction potential? Some barriers were presented – EGR distribution, combustion tradeoffs – but these are normal development tasks – not advanced R&D. Another individual remarked that the goals are nebulous, and it would be nice to see performance targets. One technical barrier is focused on wide range diesel fuel with a cetane number that varies from 42 to 58. The presentation did not directly address this variance though maybe this work was done in the past? Another possible barrier that was not mentioned is the volatility variances - does this PI believe this fuel property variance is an issue? One final reviewer stated that the presenter presents solid steps and plans how to reach the target through modeling and simulation, injector hardware optimization, and control supervisor. But they have not mentioned how to improve the charge system to improve thermal efficiency.



## 2008 Annual Merit Review

### *DOE EERE Vehicle Technologies Program*

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

One reviewer stated that this is nice application work with a focus on known problems. Another commented that the project has made excellent progress and has a good path laid out for the future. This seems to be excellent leveraging of DOE funding for a well-run project that has a good chance of technical success. One other reviewer remarked that achieving 11 bar BMEP at 3000 rpm is great. This reviewer is looking forward to the publishing of the fuel effects results, adding that there is good collaboration with LLNL on the chemical kinetics.

One person commented that the data on the alternative sensor for in-cylinder pressure sensor was slim but sounds like it is an interesting technology. More data and analysis next year would be informative. Another reviewer indicated that this project seems to still be in an early stage. For example, the variable compression ratio hardware appears to be still under development and its ability to enable HECC still has to be explored in much more detail. The presentation did not show systems integration issues for a medium-duty application; such analysis would be beneficial in assessing the actual impact of engine control/hardware changes on vehicle fuel economy. For example, it appears the engine under investigation is utilizing more and more EGR; what is the impact on cooling and parasitic losses?

One final reviewer stated very low resources are allocated – so results have been shown, but the results look like traditional development type of work. The reviewer heard that the funding level \$125K is not indicative of the total funding – if the funding level is really higher, then the results shown would be disappointing. What are the results toward BSFC improvement?

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

The first reviewer felt that this was nice application work with a focus on known problems. Another person indicated that International has a good track record of commercialization of DOE-funded results, and the company seems eager to incorporate technologies developed in projects such as this. Similarly, one reviewer stated that International appears to be on a focused path to keep the technologies they are exploring on a production viable path.

One respondent stated that portions of this overall HECC technology are likely to move into the marketplace such as variable valve timing and advanced fuel injection strategies. Other portions of the hardware development such as the variable compression ratio hardware will require much additional development beyond this program.

One final reviewer indicated that the benefits or the expectations from the project technologies shown were unclear. This reviewer does not see any real advantages to the market as a result of the work presented.

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

One of the reviewers indicated that this project seems to be severely limited by the constraints of its budget. Its results far outweigh the limited DOE investment involved. Another person added that there are very low resources allocated, but almost no results toward the objectives either. It was not clear, but seems like it may be rather low.



One person commented that this is a good program that appears to have the necessary funding, human resources, experimental, and computational resources to execution of the proposed work scope.

One final reviewer said that this was difficult to assess with the number reported for FY08.

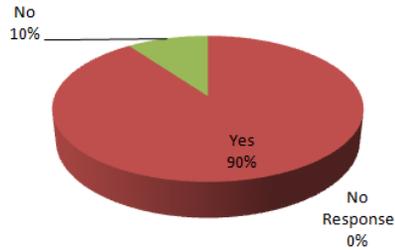
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

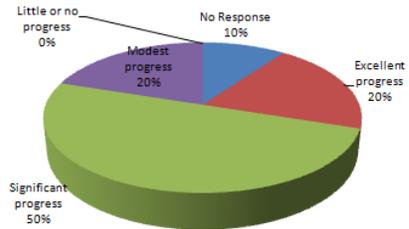


**Project: Low-Temperature Combustion Demonstrator for High-Efficiency Clean Combustion**

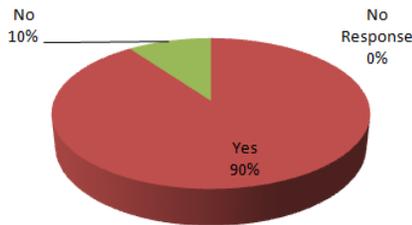
*Question 1: Does this project support the overall DOE objectives of petroleum displacement?*



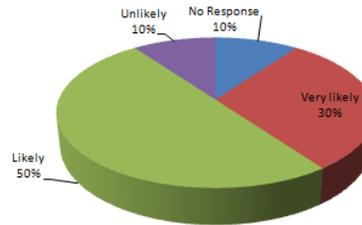
*Question 3: Characterize the technical accomplishments and progress toward goals.*



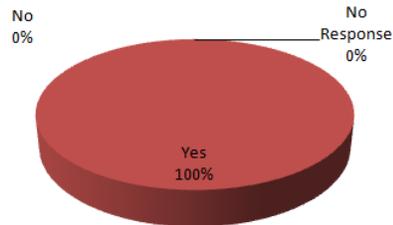
*Question 2a: Are the goals of the project technically achievable?*



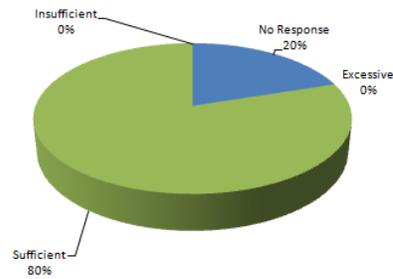
*Question 4: How likely is the project team to move technologies into the marketplace?*



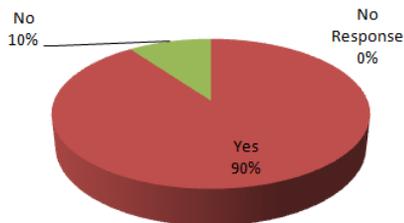
*Question 2b: Have the technical barriers been identified and addressed?*



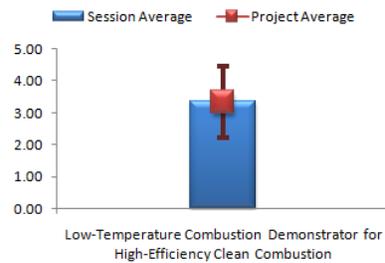
*Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.*



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



*Question 6: Overall Rating*



## Narrow-Band Engine and a CVT to Optimize Performance (Bahman Habibzadeh, of Mack Trucks Inc.)

### Reviewer Sample Size

This project had a total of 9 reviewers.

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

One reviewer stated that this will increase efficiency in diesel, while another person stated that it is an interesting approach to reaching the 10% goal. Adding to this, one reviewer commented that optimized vehicle fuel efficiency will reduce future fuel use in truck-based transportation, so looking at the vehicle as a whole is important. Another person remarked that this is a good analysis of the up-front benefits to the technology and implementation on the vehicle. This person added that a simple cost analysis is included, but no information on the whole package (CVT and vehicle integration, for example).

One reviewer indicated that, yes, this high risk concept has to be viewed from a vehicle-level perspective which, if the CVT is as efficient as advertised, should lead toward vehicle-level fuel efficiency gains without consideration of a narrow band engine. One final respondent noted that compound TC is not a new technology used in diesel engines, but it does improve engine efficiency.

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

The first reviewer stated that the goals and strategies are sound, adding that the CVT development is the responsibility of a third party and is a critical path item, especially for a late 2008-early 2009 deadline. One reviewer indicated that the compound turbine is not newly proposed technology, but there still are some barriers to be overcome / identified, such as (1) TC transient response on engine performance and (2) friction effect.

Multiple reviewers commented on proving the CVT technology. One person stated there was no info on CVT design – without the CVT's ability to keep the engine speed range narrow, this reviewer is not sure if the deployment of the technology is feasible. It seems that the concept must be integrated into a vehicle to make it work – this reviewer is not sure why this is not shown. One reviewer stated that the CVT torque limit concerns need to be addressed, while another expects the torque capability to be an issue, and a third person felt that there need to be more details on the CVT design for such high torque levels. One reviewer said the risk on the CVT is an unknown and it is not indicated as a potential risk at all. Since this approach relies on the CVT to reach the goal, it would be good to give more information about that system to understand how production-ready it really is.

One respondent said the CVT is a key part of this concept. The CVT enables narrow speed operation, which in turn enables efficiency optimizations in the engine-turbo and waste-heat-recovery turbo. But the CVT seems high risk, yet it was not included in the list of barriers. What stage of development is the Eaton CVT? Is it even possible to develop such a high-torque CVT? No information was presented on the CVT technology. Without more details, this seems like an Achilles heel of the program, and therefore there should be more focused initially on this component. At the next review opportunity, the risk involved with the Eaton CVT should be presented and discussed. In fact, why not invite Eaton to present their progress?



## 2008 Annual Merit Review

### DOE EERE Vehicle Technologies Program

One final reviewer wrote that this targeted CVT duty cycle efficiency of 95% is very optimistic. Overall program goals are contingent on the CVT itself, but work on the turbocompound device could be valuable in the future without consideration of the overall powertrain concept.

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

One reviewer noted that good progress shown on the turbo compounding, while another respondent stated the real value of this project is yet to come. We need to see the real-world CVT device to assess if the fuel economy gains are real. Simulations are valuable to assess limits on fuel economy gains, but overall integration will answer this question.

One reviewer specifically commented that the current progress is based on simulation, while another person remarked that, due to the CVT, this project has a dark cloud hanging over it and this will affect the perception of progress. One individual felt that the project has shown only modest progress – a lot of simulation and slippage of deadlines, but not much else. The efficiency improvements due to the CVT seem minimal – idle reduction gets a 5%+ improvement with minimal hardware modification. One final reviewer stated it was perhaps too early for this determination, but the preliminary work has been completed – the fully assembled engine will be more interesting.

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

The first reviewer stated that turbocompounding seems a shoo-in for implementation (low risk); however, the widespread use of CVTs in HD applications seems unlikely (high risk). This project seems to marry two completely different technologies of two widely different risk levels – is one dependent on the other, in terms of implementation? One reviewer said that Mack and Volvo have sufficient internal resources to bring these technologies to the marketplace if/when appropriate, while another person added that, if the project succeeds, since Volvo is an OEM it will be relatively easy to take it to production.

One response stated that Volvo is in a good position to commercialize the technology, adding that the big unknowns are the CVT and the turbo matching to the engine. Cost is the ultimate barrier to integration and market introduction. Another reviewer stated that torque limitations are likely to make this technology hard to adapt to HD diesel. One final reviewer commented that CVT for heavy-duty use could find its way into the heavy-duty sector in the future if its wide operating range efficiency can exceed today's finite gear range transmission technology. This program has too aggressive fuel economy goals that hinge on a narrow band engine and a very efficient CVT. Both the engine and CVT are high risk from a performance perspective viewpoint.

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

One reviewer stated that the budget seems suitable and matches the progress so far. One person added that it appears the contractor has sufficient experimental and analytical resources. They may need additional money to develop the CVT to meet the 95% plus efficiency goal. Another reviewed commented that it was stated during the presentation that 4-5 engineers were working at four Volvo centers. A total of 16-20 engineers (along with usual support staff and infrastructure) seems like a lot of work-in-kind. On the other hand, the handout did not include a dollar figure for the funding for this project, so it is really difficult to accurately rate the resource level.

Following up on this last point, one reviewer stated that no resource information was provided, and another person said that funding wasn't shown to merit reviewers for this project. Similarly, one final



reviewer stated that no dollar amount given for this year, so he or she is not sure how to evaluate this. The reviewer assumed that it is sufficient, for lack of any supporting information.

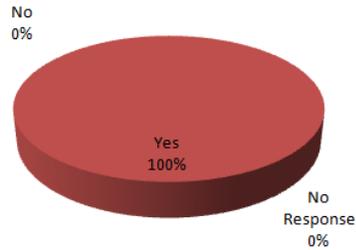
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

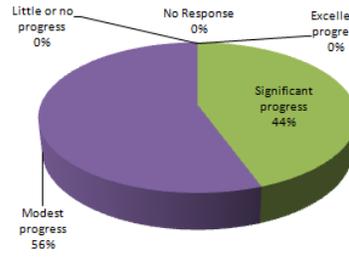


**Project: Narrow-Band Engine and a CVT to Optimize Performance**

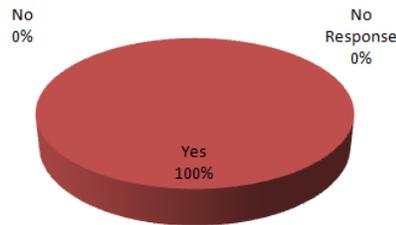
**Question 1: Does this project support the overall DOE objectives of petroleum displacement?**



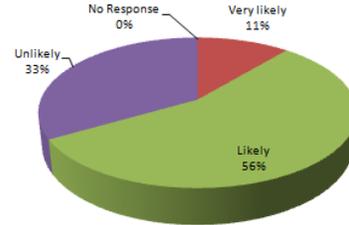
**Question 3: Characterize the technical accomplishments and progress toward goals.**



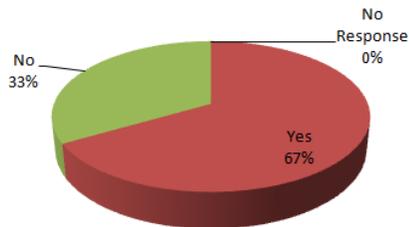
**Question 2a: Are the goals of the project technically achievable?**



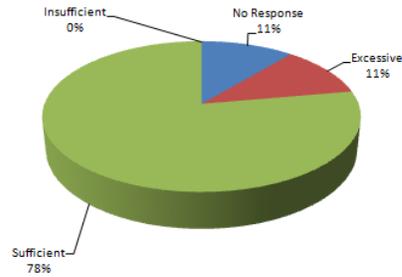
**Question 4: How likely is the project team to move technologies into the marketplace?**



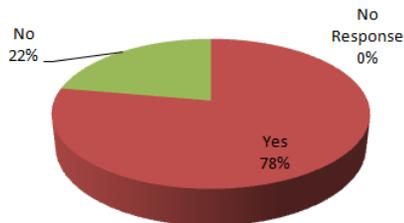
**Question 2b: Have the technical barriers been identified and addressed?**



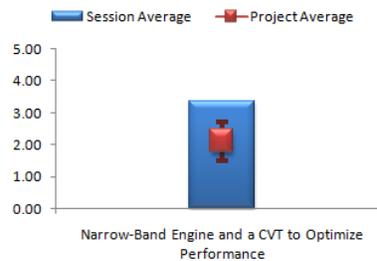
**Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.**



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



**Question 6: Overall Rating**



## On-Board Engine Exhaust Particulate Matter Sensor (Matt Hall, of University of Texas at Austin)

### Reviewer Sample Size

This project had a total of 12 reviewers.

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

Results to this prompt were generally positive. One reviewer stated that it supports an enabling technology for diesel, while another believes that a real-time PM sensor can be important in mixed-mode combustion, adding that this could be an enabling technology. One person stated that it helps in the monitoring and feedback control of LTC engines to minimize PM emissions. Another commented that a PM sensor is an auxiliary for HECC/HCCI and diesel engines. One response stated that there are very promising results for not just LTC, but also conventional direct-injection gasoline development. One other reviewer commented that an on-board PM sensor would be useful in developing control strategies to meet PM emissions from diesel engines.

One respondent stated yes, but only indirectly – it is an enabling technology that may or may not be of interest to OEMs (how many OEMs plan to use NOx sensors in near-term production, for example?).

One final reviewer asked: Why is there no correlation of the PM sensor to opacity or PM measurements or smoke? What is the potential of the technology? Why does it support DOE objectives? Since the developers are not sure how the technology works – why not study this and make sure the concept is understood and proper correlations are made to avoid wasting time and resources?

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

The first reviewer indicated that the approach proposed is feasible, while another noted that this sensor is of interest for advanced combustion technologies. One other reviewer commented that various designs of sensors are being constructed and tested. One person remarked that good progress has been made with the design improvements made from the original concept. It is good to see a sensor manufacturer show some interest in this and contribute their expertise to this project.

Another reviewer commented that the need for good sensors is vast. The vehicle manufacturers are responsible for maintaining and diagnosing emissions. Filter regeneration is difficult and this will help. One response stated that it will be critical for the success of the project to develop a better understanding of the underlying physics of the sensor; otherwise a cut-and-dry approach is unlikely to overcome the significant technical challenges. Similarly, one reviewer said it is still not clear that the physics are well understood. Further investigation here may result in a more robust product.

One respondent wrote that it is not clear what is different and better about this sensor over other sensors being developed. One final reviewer asked: why is there no correlation of the PM sensor to opacity or PM measurements or smoke? What is the potential of the technology? Why does it support DOE objectives? Since the developers are not sure how the technology works – why not study this and make sure the concept is understood and proper correlation is made to avoid wasting time and resources?



## 2008 Annual Merit Review

### *DOE EERE Vehicle Technologies Program*

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

One reviewer stated that the results have shown linear volt-soot mass behavior, adding that this is impressive work. Another person commented that the design has evolved considerably since the last review.

One other response indicated that the design improvements for reliability look to be on target. It would be nice to see better correlation with some standardized PM sampling method. One reviewer added that more improvement in design is still desired to capture PM signal constantly, adding that the project has lot of works to do before calibration.

Another response stated that greater fundamental understanding of the electromagnetic aspects of this technology is essential to overcome issues of reliability, drift and potential degradation. Foil electrodes sound too fragile for commercial use – what about thick, curved stainless steel electrodes set in a ceramic rod? Similarly, one reviewer asked, since the developers are not sure how the technology works – why not study this and make sure the concept is understood and proper correlation is made to avoid wasting time and resources? Why is there no correlation of the PM sensor to opacity or PM measurements or smoke? What is the potential of the technology? Why does it support DOE objectives?

One final reviewer noted that the project is still in the start-up phase, which is understandably slower. Setting up a multi-cylinder engine and controlling it under multi-mode (diesel/HCCI) operation are substantial tasks that will require time. Unfortunately, this will take away time and resources from the development of the sensor. This reviewer asks: would it be possible to focus the project on sensor development and collaborate with another academic group and/or industrial partner to evaluate the sensor in a multi-cylinder engine? This should include consideration of the effects of engine vibration on sensor life, as well as an exploration of sensor performance in transients.

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

The first reviewer stated that this project addresses a big need and seems inexpensive, while another reviewer commented that an operating, reliable, low cost sensor will provide its own marketing.

One respondent remarked that deployment is likely, provided that strong partnerships with OEMs are developed. Cummins' early involvement in the project and the recent interest by Ceramatek are encouraging. Another indicated that work is being done in collaboration with Cummins. One person commented on the need to increase the activity with a sensor manufacturer, while (in contrast) one person stated that the strong interest apparently from both an engine OEM and sensor manufacturer makes this already a reality. With more reservation, one response indicated that, at the very least, this type of sensor would be useful for the development of DI engines, both gas and diesel.

One final reviewer asked: why is there no correlation of the PM sensor to opacity or PM measurements or smoke? What is the potential of the technology? Why does it support DOE objectives?

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

One reviewer stated there that has been good progress for a small program, while another similarly remarked that there has been good progress on a limited budget. One person stated that the resources are appropriate for the project's objectives related to sensor development. Leveraged funds will be



required for the setup of a modern multi-cylinder diesel engine facility, or the latter should be pursued through collaboration with a partner.

One final reviewer commented on that very limited funding – the presenter mentioned correlation data would be included in the upcoming SAE meeting. In this DOE review, several presenters mentioned the data would be published in SAE papers – why not present technical results at these DOE sessions? The lack of technical data is disappointing.

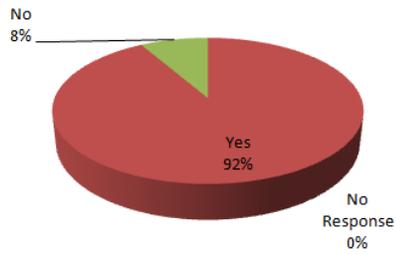
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

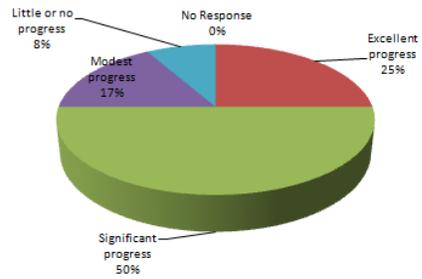


**Project: On-Board Engine Exhaust Particulate Matter Sensor**

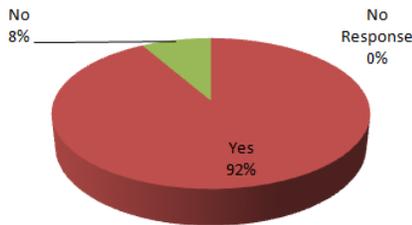
*Question 1: Does this project support the overall DOE objectives of petroleum displacement?*



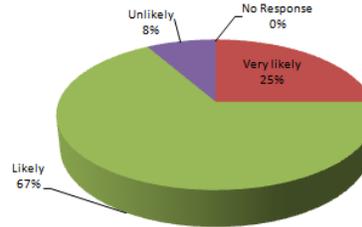
*Question 3: Characterize the technical accomplishments and progress toward goals.*



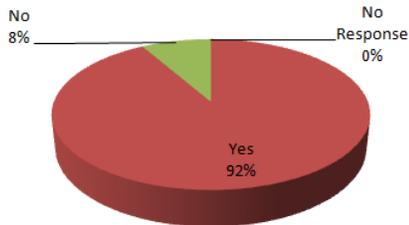
*Question 2a: Are the goals of the project technically achievable?*



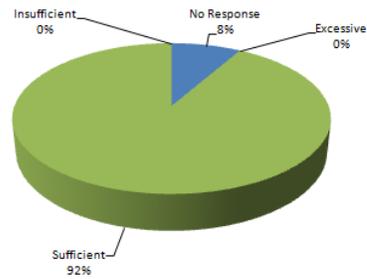
*Question 4: How likely is the project team to move technologies into the marketplace?*



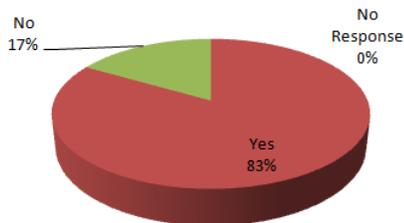
*Question 2b: Have the technical barriers been identified and addressed?*



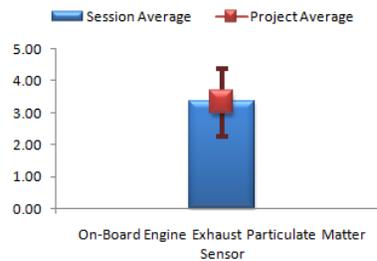
*Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.*



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



*Question 6: Overall Rating*



## Variable Valve Actuation (Jeff Gutterman, of Delphi Automotive Systems)

### Reviewer Sample Size

This project had a total of 13 reviewers.

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

One reviewer commented that the group is working on VVA hardware development to enable LTC and HCCI, while another person stated they are working on a mechanism to enable VVA to enable LTC combustion. One respondent commented that VVA is one of the "holy grail" quests for advanced combustion. Another response stated that the benefits of VVA on opening up opportunities for efficiency improvement are well documented. One other reviewer remarked that the project is developing critical to VVA hardware for production-intent LTC/HCCI engines, thus supporting the DOE fuel economy objectives. Another person commented that VVA is potentially important technology for enabling LTC or mixed mode operation, as well as improving the fuel efficiency of conventional engines. Applications to CI and SI engines are equally applicable. One reviewer noted that the VVA project was initiated to support VT High Efficiency, Clean Combustion Enabling Technologies. The group is working to develop a practical, production-worthy VVA system that will have widespread use across many engine platforms.

To contrast, one reviewer stated yes, but specific designs can be difficult to incorporate into the existing OEM architecture. One final reviewer didn't know – slides claim that the VVA advantages are well known – but also that a compromised VVA system that is feasible is better than an idealistic VVA system that is never produced commercially – but the compromised VVA design should outline specific advantages and objectives. This reviewer added that in the future DOE should have each presentation outline specific quantitative targets/goals/metrics for clarification purposes.

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

Multiple reviewers commented that this project is a realistic and practical approach to get an affordable system for use in IC engines. Another reviewer commented that the project is using an appropriate balance of simulation tools and hardware development. One person stated that production feasibility seems close.

One reviewer noted that the technology is being designed into a GM engine – this is good. It is also being designed into a cradle that can be tuned to other engines easily – this makes sense. How does this compare to other commercially available VVA (lift and timing) systems (BMW, Nissan, Toyota...)? Another reviewer indicated that Delphi has made excellent progress on making this technology viable for a production engine. One final reviewer noted this could be used for a variety of purposes on both exhaust and intake cams.

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

One reviewer commented that the program appears to be on schedule and meeting its goals for providing a viable VVA enabling technology for OEMs. Another person indicated that this is a relatively low cost idea that seems to have some potential, while one other person stated that the flexibility looks good and consistent with Russ' presentation on IVC techniques from GM. One reviewer remarked that multicylinder engine operation is the next important step in this development program.



## 2008 Annual Merit Review

### *DOE EERE Vehicle Technologies Program*

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One response noted that the product is being used in dynamometer testing, while another stated that the project seems to have come to a conclusion.

One final reviewer commented that the project has benefited from the collaboration with GM. Collaboration with more OEMs would be desirable to develop hardware that could support a range of VVA strategies contemplated by various OEMs. Exploration of benefits on the diesel side has yet to be done. This reviewer added that the project should report on benchmarking against other production-intent systems reported in the literature and articulate its advantages/limitations.

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

The first reviewer stated that this is a realistic approach. Another respondent commented that this is a cost effective mechanism compared to full camless. One person felt that this technology can be deployed and if the mechanism is cost effective and can be packaged. Another reviewer stated production feasibility was designed in from the start.

One reviewer noted that Delphi is working directly with one of the OEMs (GM) to support its programs. Similarly, another felt that Delphi seems to be keen on commercialization, and so we can conclude that technology transfer and market introduction is only a matter of time. One person stated that this looks to be a very viable option for doing VVA in a production environment. More specific information on interactions with OEMs would be helpful to know how close this really is to commercial production.

One individual commented that the cost/package/complexity looks very high. Another person added that the key issue is cost – every diesel engine already has significant cost issues, and VVA increases the complexity and cost. This reviewer added that other aspects of the program seem well-suited for commercialization. One final reviewer stated that the benefit of the system does not appear to be worth the cost, weight, and packaging space issues that come with it.

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

One reviewer stated that the resources are appropriate for the project's objectives over the duration of the program. Another person stated that the DOE funding seems to be well-leveraged and well used. One final reviewer added that the accomplishments look good for the modest funding level (at least in FY08).

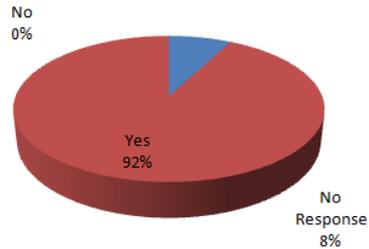
**Question 6: Summary rating: when scoring this project, consider the relevance of the work to DOE's objectives, potential impacts on DOE/VT goals, project accomplishments, likelihood of technology transfer, and sufficiency of project resources.**

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

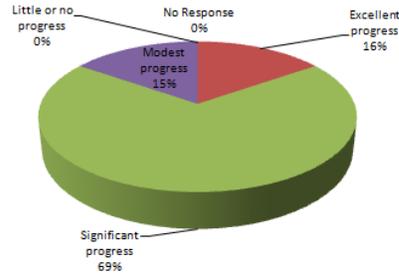


Project: Variable Valve Actuation

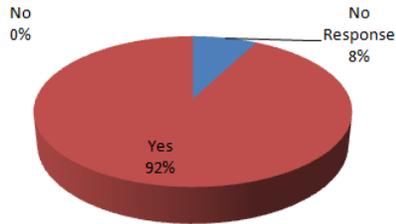
Question 1: Does this project support the overall DOE objectives of petroleum displacement?



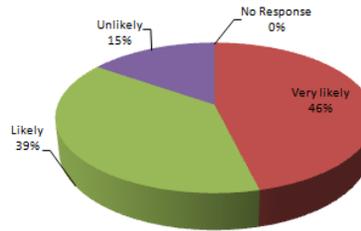
Question 3: Characterize the technical accomplishments and progress toward goals.



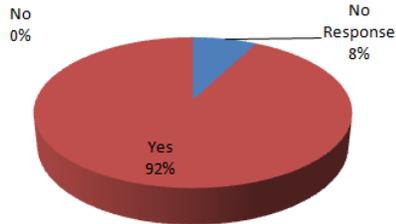
Question 2a: Are the goals of the project technically achievable?



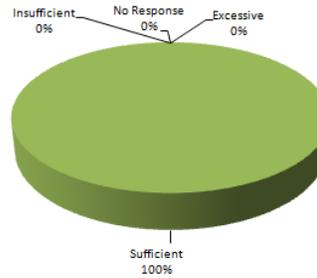
Question 4: How likely is the project team to move technologies into the marketplace?



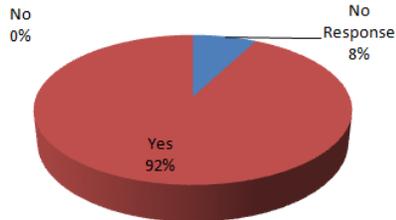
Question 2b: Have the technical barriers been identified and addressed?



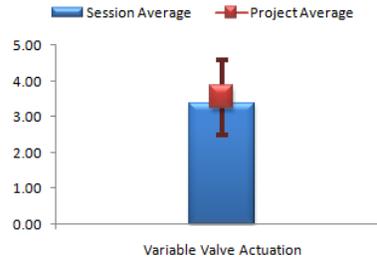
Question 5: Characterize the resources available for this project to achieve the stated milestones in a timely fashion.



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



Question 6: Overall Rating



# 2008 Annual Merit Review

*DOE EERE Vehicle Technologies Program*

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