Work Assignment 2-05 under
CONTRACT 68HE0C18C0001

EXTERNAL PEER REVIEW OF "HEAVY-DUTY ENGINE VALVETRAIN TECHNOLOGY COST ASSESSMENT"

PEER REVIEW REPORT
February 22, 2021

Submitted to:
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1.0 INTRODUCTION

This report documents the results of an independent external peer review of the draft report, *Heavy-Duty Engine Valvetrain Technology Cost Assessment*, developed by FEV North America, Inc. (FEV) for the U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality (OTAQ).

Eastern Research Group, Inc. (ERG, a contractor to EPA) organized this review and developed this report. The report provides background about the review (Section 2), describes the review process (Section 3), provides a high-level summary of reviewers' comments (Section 4), and includes reviewers comments with EPA's responses (Section 5). Appendix A provides resumes for the selected reviewers, and Appendix B provides the charge to reviewers. Reviewer comments are presented exactly as submitted, without editing or correction of typographical errors (if any).

2.0 BACKGROUND

EPA's *Heavy-Duty Engine Valvetrain Technology Cost Assessment* is a key milestone in an extensive effort being carried out by FEV, under contract with EPA, to estimate the costs of technologies likely to be used in meeting future heavy-duty highway vehicle criteria pollutant emissions standards, with a particular emphasis on technologies that reduce NOx emissions over a broad range of operating conditions. The report details the methodologies used by FEV and its subcontractor(s) to determine a cost for various heavy-duty emission control strategies and report the results of this work to date.

The Technology Cost Report identifies all component systems and subsystems, and conducts an engineering evaluation/cost analysis of specific technology packages. These costs are heavily driven by engineering design choices and decisions that include projections of design, materials, and fabrication optimization potential for these technologies as they reach large-scale production.

The technology package was evaluated relative to a baseline technology for heavy-duty truck applications that is representative of the current state of design, and the baseline and new technology heavy-duty trucks having similar overall utility. For this study, EPA's contractor developed estimates for direct, indirect, and operating costs other than fuel costs. With respect to indirect costs, EPA's contractor estimated the incremental change in indirect costs for each sub-category of indirect cost which are projected to change as a result of the production of the new technology.

For this study, EPA's contractor evaluated the potential of, and projected costs for, the production of these heavy-duty truck technologies in the 2027-2030 timeframe. For promising technologies not expected to have fully matured within this timeframe, the evaluation was for the longer term (at full technology maturation--high volumes, designs and fabrication processes optimized, initial R&D and capital investments recovered).

3.0 PEER REVIEW PROCESS

EPA tasked ERG with identifying three or four reviewers who had no conflict of interest (COI) in performing the review and who, collectively, met the following selection criteria:

- Familiar with manufacturing cost estimating.
- Powertrain design and operation.

ERG initiated a search process, asking interested candidates to describe their qualifications and respond to a series of "Conflict of Interest" (COI) analysis questions. ERG carefully screened submissions to identify a pool of qualified, COI-free candidates. From this pool, ERG selected the three experts (listed below) who collectively best met the selection criteria. ERG contracted with the reviewers after EPA verified that they were appropriately qualified.

- **Robb Janak, B.S.**; Director - New Technology, Jacobs Vehicle Systems
- **James E. McCarthy, Ph.D.**; Chief Engineer, Eaton Corporation
- **Greg Shaver, Ph.D.**; Professor, School of Mechanical Engineering, Purdue University

ERG provided reviewers with the review document and the technical charge to reviewers (Appendix B). Prior to the start of the review, ERG organized and facilitated a meeting between reviewers and EPA to provide reviewers an opportunity to clarify their responsibilities for the review. EPA provided background about the review document and responded to reviewers' clarifying questions. Reviewers then worked individually (i.e., without contact with other reviewers or EPA) to prepare written comments. During this time, one reviewer sent a request for additional materials to ERG. ERG forwarded this request to EPA and provided EPA's response to all three reviewers. Reviewers completed their individual reviews and submitted their written comments to ERG. ERG consolidated reviewers' comments into an Excel comment spreadsheet and provided it to EPA. EPA's contractor FEV requested additional references mentioned by one reviewer. ERG facilitated EPA's request by contacting the reviewer, receiving the references from the reviewer, and then providing those references to EPA. EPA then responded to reviewers' comments and provided a response to comments document, prepared by FEV, to ERG. ERG then prepared this report, including the high-level summary of reviewers' comments (Section 1.3).

4.0 SUMMARY OF REVIEWER COMMENTS

Summary of Reviewer Comments

This section provides a high-level summary of the comments provided by the three peer reviewers, Mr. Robb Janak, Dr. James McCarthy, and Dr. Greg Shaver. EPA's charge to reviewers asked reviewers to comment on all aspects of the report, with a particular emphasis on the cost methodology and associated information sources. EPA's charge also asked reviewers to distinguish between "recommendations for clearly defined improvements that can be readily made, based on data or literature reasonably available to EPA" and "improvements that are more exploratory or dependent, which would be based on information not readily available to EPA."

In comments concerning their overall perception of the analysis, reviewers reacted positively to both the bottom-up approach described in the report and to the report's level of detail. They provided a wide variety of comments, however, given the wide range and small number of reviewers, no two reviewers commented on the same specific aspect of the report. Approximately half the comments concerned recommendations or suggestions for improvement to the cost or technical analyses. The remaining comments pointed out elements of the report that would benefit from clarification, provided general opinions or ideas, or discussed items of interest that may not necessarily be within the direct scope of the report.

Cost Methodology

Mr. Janak and Dr. McCarthy indicated that the cost methods and estimates were largely sound. Dr. McCarthy commented that "the cost analysis was well done" and provided more detailed generally positive comments on several key aspects. Dr. Janak commented that the approach of conducting a comprehensive cost-up analysis for a few technologies "can support informed decisions about the relative costs of the chosen technologies," but was concerned that the designs used for the two benchmarks appeared to be a very different levels of demonstration and technical maturity, creating a risk of undercounting the cost estimates. He noted some other concerns as well. Dr. Shaver did not provide overarching comments.

Reviewer-suggested improvements generally focused on small details of the analysis (i.e., changes to improve correctness and completeness) that would likely not significantly affect the report's findings. When commenting on specific part-level cost estimates for the candidate technologies, reviewers generally indicated that they seemed either reasonable or low compared to their expectations; no reviewer indicated any of the cost estimates seemed high. Reviewers also commented on the scope of the work; these suggestions generally centered around the inclusion/exclusion of certain technologies and manufacturers or around the cost basis assumptions such as where the boundary around the cost analysis was drawn, especially regarding included production costs versus excluded tooling costs. Only a few minor comments were provided regarding information sources for the cost methodology. Specific recommendations and suggestions for improving the cost methodology are summarized below.

Recommendations for Clearly Defined Improvements

Many of the suggestions in this category involved extremely specific details on the manufacturing processes of some parts in the bill of materials, including specific material types, heat treatment, and forming processes such as grinding and machining. Mr. Janak commented on the costs of approximately ten specific (and generally small) parts. In all cases, he indicated that the cost estimates seemed low compared to his experience and he provided a potential reason for the discrepancies.

Dr. McCarthy was generally more in agreement with the costing results, but recommended that some costs be presented on a per-cylinder basis, which would potentially allow more relevant comparisons across different engine layouts. He also suggested deploying some of the relevant technologies on a subset of engine cylinders to capture similar benefits at lower cost. Dr. Shaver provided no comments in this category.

Improvements that are More Exploratory or Dependent

Reviewers made very few suggestions for exploratory or dependent improvements. These suggestions tended to be more abstract, involving aspects of the report in which the reviewer was not necessarily in disagreement with the approach but noted a concern for further review. Topics for which reviewers suggested improvements included the assumption that costs necessarily decline from the point of early technology demonstration, the costing balance between tooling and manufacturing costs, and whether the technology implementation may have subtle effects on wider aspects of engine operation that would be difficult to consider accurately.

Comments Concerning Corrections and Clarifications

Many reviewer comments concerned suggestions to improve the assessment's usefulness, accuracy, and readability. All reviewers pointed out instances in which the assessment's content could be made clearer or where interpretations regarding engine functions or technologies could be made more technically correct. The assessment contains many complicated details regarding different engine sizes and configurations, acronyms, and engine parts, and reviewers made suggestions to either correct apparent errors or help the reader follow the analysis. For example, reviewers presented ideas on places where assumptions for one engine may not apply to another, or where certain components were not necessarily appropriate for the technology being applied.

5.0 NARRATIVE COMMENT AND RESPONSES

5.1 Comments Submitted by Mr. Robb Janak

5.1.1 General Comments

The direction to target a few technologies and do a comprehensive cost-up analysis, is an interesting direction and I believe can support informed decisions about the relative costs of the chosen technologies.

However, the designs used for the two benchmarks appear to be a very different levels of demonstration and technical maturity. Because of this, there is a risk of undercounting the cost estimates, because they should utilize different adjustment factors for their relative technical risk. There are also other designs in the marketplace that accomplish similar functions, and are at different cost and technical maturity. Though it appears to be out of the scope of this cost estimate report, It is important that these factors and options are more clearly address when these results are summarized. Otherwise there is a risk to associate only these mechanism and designs.

Also, as I noted below, I think it is important to reference the other industry cost assessments that focused more on a technology price -down method.

> **EPA's Response:** Indication on the difference in technology maturity between CDA and LIVC is provided in the third paragraph of section 1.B. Estimated range of cost for OEM to adapt these technologies is also provided.

5.1.2 Summary Comments

The brake module creates an inconsistency with assessing the incremental cost of adding CDA for the X15 configuration. I see the statement made in Table 6-2, saying that the new design was warranted due to packing. However, since this brake design has a lower calculated cost, it lowers the total cost of the CDA + Brake combined system, thus confounding the incremental cost of the CDA technology. Therefore, to make the assessment comparable, either the X15 baseline brake costs should be used in the CDA system cost, or the CDA Brake design should be included in the X15 baseline, or the brake could be removed entirely for the assessment.

A cost reduced brake design should not confound the incremental cost of the CDA technology, unless there is a interdependency on the system to enable the function of CDA. Conversely, any proposed cost reductions could be realized at any time, independent of the CDA system implementation.

Another direction would be to include an analysis of one of the variants above. This report uses this exact direction for the removal of the cam bearing for the LIVC cost analysis. Both options were provided, and then the receiver of the report can decide the feasibility of the options provided, or what correction factors should be applied to the final results.

EPA's Response: As CDA design inevitably changes cylinder head design, this provides an opportunity for change in brake rocker arm design. In baseline technology, supplier tends to use old cylinder head and rocker arm designs.

When I suggest a correction, I added other locations where this edit could be made, but for a numeric value that will affect multiple charts and summaries, I assume the author will find all the instances.

EPA's Response: All the relevant cost tables were updated.

I listed several questions and concerns on the cost estimates, as the majority seemed much lower than my experience. I listed several examples, but did not do this for every component, as it appears that there are additional assumptions or experience in the manufacturing models used. I am unsure, but it almost seemed that some of the cost estimates were more aligned to automotive manufacturing process that leverage much higher volume systems, not conducive to the HD Commercial engine manufacturing volumes. I understand the assumptions listed were to be matched to a 30,000 engine annual volume, but I can only comment on my experience.

There are some components, or even commonize features, that could capitalize on extensive process optimization to get closer to realizing some of the costs outlined here, but the larger portion of these parts are isolated and suppliers are often held to customer specific requirements, that make achieving these optimized costs extremely difficult.

EPA's Response: In comparison to higher volume systems, current study employs higher material, labor and MOH rates to account for low volume scenario. This was done to account for reduction in efficiency and utilization of labor and process machinery. Though its true that indirect OEM manufacturing cost is comparably higher for low volume and new technology scenario, this is not considered in piece price study.

Executive Summary, Para after Figure 0-3: Baseline cost assessment used the Duramax 6.6L engine valvetrain. As this is a V8 6.6L, and the L9 is a 9L I6, there should be some size/mass scale factor, or a reference to a comparable spec limits.

For example, HLA load requirements will be set at max engine speed and valve spring preload. There are other factors, but they would require additional analysis, and these two factors should give an indication of the size scale factor.

EPA's Response: Duramax 6.6L is taken as basis to cost rocker arm components only. For all other components X15 is taken as basis. Additional components for Hydraulic roller lift mechanism is taken from CDA design provided by Eaton, specific to X15 engine.

Table 1-1, Item 1: General concern that Cost analysis shifts tooling to OEM. This will overall lower the S&G artificially and may be a poor comparison for technology where a supplier needs to control the tooling intrinsic to the developed technology and may contain IP or Trade Secrets.

I understand that this is the baseline EPA is requesting, but this should be noted as a technology cost addition to how this data is managed into a final summary. I'm not familiar with the ICM Factor and if this will cover this factor.

> **EPA's Response:** Yes, ICM factor would usually represent added technology cost to product cost. More about ICM can be found in last paragraph of Section 1.B.

5.1.3 Technical Comments

Table 4-2, Item 06-36: There is not enough information to assess this, but it seems to align close to just the Brake Oil Control Valve from the X15 Base (Item 06- 27 thru 39) . So with item 06-40 and 06-41 removed, the cost would be $10.75. So it seems to be off only a few cents

> **EPA's Response:** Yes, brake OCV is assumed to be same for all 3 types of valvetrains. The slight difference is a result of a marking up error, which has been corrected.

Table 1-1, Item 2: Product/Technology Maturity Level: Even though the analysis assumption is for a 'Mature Technology' , there should be allowance for additional margin or hedge, for New Technology introduction, especially since the systems used in the cost analysis are not mature. Costs generally increase from the earlier technology demonstrators. Along with this, additional margin needs to be reserved for the uncertainty and risk associated with any application launch, which increases warranty exposure, until a large population of products and applications establish the reliability. I would suggest that an additional factor for technology cost uncertainty, and an additional factor for warranty be added (both only on the New Technology content).

As noted previously, perhaps this is captured in the final summary and/or ICM Factor that will be applied to the reports values, but this was not suggested or offered in this element.

> **EPA's Response:** Eaton's CDA and Mechadyne's LIVC are assumed to have same technology maturity. Learning factors relevant to new technology costs are provided in the last paragraph of Section 1.C.

Attribute and Cost Summary Overview Tables, Item 9: 'Harness' was identified in Table 0-4, Fig 0-2, Table 0-5 and Fig 0-3 as a line item and incremental cost for CDA over baseline. Therefore, this needed to be identified as a line item here, and as 'Included in Analysis'.

> **EPA's Response:** Corrected.

Attribute and Cost Summary Overview Tables, Item 9: All of these elements are titled ' Not included in Analysis': Intake Valve, Exhaust Valve, Valve Cover, Valve Spring, Spring Retainers, Cotter, Spring Seats;
If these are not included, then the costs of these parts should be removed from all of the system and comparison cost tables, especially since none of these are expected, nor shown in this study, to change with the technologies of interest.

> **EPA's Response:** Though its true that cost of these components remain same for all 3 technologies evaluated, including it would help us get to the cost of total valvetrain, which is a good data point to understand the cost assumptions.

Attribute and Cost Summary Overview Tables, Item 9: 'Sprint Seats' should be 'Spring Seats'

EPA's Response: Corrected.

Table 3-1: Cross-drill in Brake rocker arm is used to send pressurized oil for *EEVO' is a confusing statement as EEVO is termed used for opening the Exhaust valve 0-80degrees earlier than normal opening, to provide thermal management during combustion, and therefore a different technology. This function does not exist in the baseline X15 engine, and the brake rocker arm does not send 'pressurized oil' for EEVO. the only oil passage in the brake rocker arm, is to receive oil from the oil control module to activate the engine braking function.

EPA's Response: Yes, EEVO isn't the right technical term here. Corrected.

Table 3-3, Item 03-09: $1.21 seems low for 6 hardened steel bushing. The cost assumed here appears to be for a plain steel bearing.

EPA's Response: Heat treatment step is added to the process flow and cost is updated. It is to be noted that tooling cost isn't included in this analysis.

Table 3-3, Item 04-19: $1.36 seems low for 6 hardened steel bushing. The cost assumed here appears to be for a plain steel bearing.

EPA's Response: Heat treatment step is added to the process flow and cost is updated. It is to be noted that tooling cost isn't included in this analysis.

Table 3-3, Item 05-25: $1.22 seems low for 6 hardened steel bushing. The cost assumed here appears to be for a plain steel bearing.

EPA's Response: Heat treatment step is added to the process flow and cost is updated. It is to be noted that tooling cost isn't included in this analysis.

Table 4-2, Item 04-34: $31.74 appears low, when compared to the baseline X15 (Table 3-3 #04-20 @$41.46); Steel Forgings are typically cost 30-60% more for the equivalent weight, because the tool can only fit 2-4 piece per die, when in a casting can support a factor of 4 of this.

Secondarily, the machine tooling costs can be 2-4x for machining heat treated 4140 steel over Cast iron, depending on the hardness's used. Blind bores and long drill do not follow machine handbook cutting feedrates because of the complexity of coolant and chip evacuation.

Lastly, both systems would have the same shaft bore, roller pin, and slot which constitute the bulk of the machining. The primary actuator bores between the systems appear to have a slight size difference, but the bulk material removal would still be substantially the same, where a casting could have additional material cored and a forging could not. So even with the weight reduction, I would not expect this to be less costly than the baseline example.

EPA's Response: Finish mass of exhaust rocker arm in CDA valvetrain is almost half of baseline rocker arm. Moreover, CDA valvetrain employs a different and much simpler design for engine braking resulting in lower machining time compared to baseline. It is to be noted that tooling costs were not considered for either sand-casting or Forging. Tooling is considered to be covered by OEM and is not included in the piece price study.

Table 4-2, Item 05-35, Item 03-20: $49.08 for Exhaust rocker and $57.45 for the Intake rocker arms cost when compared to X15 baseline ($33.59 and $35.42 respectively) also seems low. Again, I expect the forging raw part costs to be 40-60% higher as noted above. The CDA function requires additional strength, so the rocker arm hardness will be higher, which will yield higher tooling costs, along with the extra features and blind bore and drilling complexities noted previously.

Since I assume the same machining assumptions were used with these units, as the brake rocker arm above, I would suggest a re-assessment of the feedrates and tooling costs.

EPA's Response: Same comments as above.

Table 4-2, Item 05-18, Item 03-18: $9.30 Seems low for a thin-walled steel part that has a lot of material removal. I also expect costs for if it required both heat treatment and secondary hard-turning for the OD and controlled stop-lip.

EPA's Response: Material removal, heat-treatment and Grinding operations were considered in the analysis. Cost of tooling isn't considered in the analysis.

Table 4-2, Item 05-19. Item 03-19: $11.39 Seems low for a thin-walled steel part that has a lot of material removal. Costs would also increase, as I expect it to be heat treated and a secondary OD grinding to create a proper slip fit and OD honing for the sliding fit of the Internal Resting housing

EPA's Response: Material removal, heat-treatment and Grinding operations were considered in the analysis. Cost of tooling isn't considered in the analysis.

Table 4-2, Item 06-37/OCV Mounting: $31.01 seems low, when compared to the baseline X15, which is $10.03 for one housing with one bore. $31.01 for 4 housings (=$7.75 each) with each housing having two bores, appears undercounted.

Both the baseline and the new design use the two bolts to hold the housing. But the new CDA OCV housing needs to accommodate two solenoids, so it needs more material wrap. It has more raw material and more machining

EPA's Response: Baseline OCV Mounting is made of Powder metal and hence has higher cost than CDA OCV mounting which is sand-cast and machined.

Table 4-2, Item 09-40/Harness: Need description somewhere- perhaps Table 6-1, to describe the incremental changes for the harness. Is there an incremental change for the brake assumption for the CDA system, or is this only for the 6 CDA solenoid connections?

EPA's Response: Reasons for difference in cost of harness for 3 technologies evaluated is provided in Table 6-2 Item #9. Harness cost in CDA valvetrain includes both brake and CDA related connections.

Tables 3-4 & 4-3, Item 03, Item 05: It was difficult to assess the changes when the terminology of the subcomponents were not consistent, and there was no picture in the appendix to reference the baseline design (Fig 2-3 shows the CDA design elements). This needs to be included in order to ensure all parts are represented and to valuate the cost changes.

Recommend that the item numbers be aligned to match the equivalent elements from Table 3-4 and Table 4-3. Items #03-3 and 03-5 already match, but the rest do not.

Item 03-10 and 05-10 (Table 3-4/ Baseline) = Bolt, does not seem to be represented in the CDA Table 4-2. I assume that this is the rocker arm insert that in pressed into the rocker arm to interface with the Pushtube. This feature should not change for the CDA valvetrain , and there were no items that had a similar name or cost.

Item 03-6 and 05-6 (Table 3-4), I assume is the Hydraulic Lash Adjuster (HLA) assembly. To be comparable to the CDA enable elements in Table 4-2. These 03-6 and 05-6 items should be broken to similar elements found in Table 4-2. This is to ensure all parts are included in the cost estimate and to make it clear what elements are changing in the valuation.

> **EPA's Response:** Pictures of type V valvetrain components that are different from type III valvetrain are added to the appendix. Cost of bolt added to the CDA type V valvetrain.
> Figure 8-6 in Appendix highlights the components with similar functionality for type V baseline vs CDA components.

Table 5-2, Item 05-28: the narrow nature of this roller makes me think that it will not follow normal roller grinding process and will likely cost more to produce. The excessively low Length/Diameter will not allow normal centerless grinding to impart a crown, so additional processing may be needed.

> **EPA's Response:** Cost includes ID grinding, OD grinding and Surface grinding. It is to be noted that tooling cost is not considered for this analysis.

Table 5-2, Item 09/Harness: Since the baseline has the standard engine brake, and has no cam phaser, it seems like there should be a change here. I saw the note on page 49 (Table 6-2) that says "LIVC valvetrain requires same harness for OCV as that of Baseline valvetrain ", but there should be a connection to the FlexValve Actuator that is in addition to the baseline harness.

> **EPA's Response:** Harness cost in this section previously represents the cost to actuate OCVs in valvetrain system of the engine. Connection to FlexValve actuator is now included as part of the FlexValve actuator cost as it gets integrated to engine harness.

Section 7, Para after Figure 7-1: 'CDA is limited for use up to 3-4 bar.

That is the limit for various fixed CDA modes. Dynamic CDA has been demonstrated to a larger operating range of 1800rpm and up to 5.5bar BMEP.

> **EPA's Response:** Upon confirmation from Eaton, max BMEP is changed to 5.5bar at 1800rpm.

Table 5-2, Item 05: As I mention in previous notes, I think raw material and machining costs of the #05-21/ FlexValve Rocker arm and #05-22/ Output rocker arm may be undercounted. I expect that these parts will need higher strength than the Baseline intake rocker arm, due to the hand-off loads and narrow connection of the two rocker arms together. Stronger material, will increase machining and tooling costs.

> **EPA's Response:** As suggested by Mechadyne, these components are assumed to be made of sand-casting. Raw material and machining costs were evaluated accordingly.

Table 5-2, Item 05-30, Item 05-31: As I mention in the Baseline configuration, these cost estimates seem to assume plain Steel bushing, not hardened steel bushings. As the rocker shaft loads are assumed higher for this configuration, I assume that this FlexValve system would require hardened bushings.

> **EPA's Response:** Heat treatment step is added to the process flow and cost is updated. It is to be noted that tooling cost isn't included in this analysis.

Table 3-2: 'Camshaft and all rocker arms are sand-cast, machined and heat treated': Cast Iron rocker arms arm typically not heat treated, and are 'as-cast' unless they need additional strength and would then have a higher hardness. I do not believe these rocker arms are heat treated.

> **EPA's Response:** Heat treatment cost not included in the initial cost assessment for rocker arms. Apologize for the wrong wording. Corrected in the final report.

Table 3-3, Item 03-10: Material Listed as 4140 Steel, Sand casting. But the actual material is a Ductile Iron sand casting. I'm not as familiar with 4140 casting, but because of the alloy nature of 4140, and that less scrap metal can be used in the melt, I would expect that Ductile iron should be less expensive raw material.

> **EPA's Response:** Previous spectrometer reading might be skewed due to the coating on the part. Upon review, the material part is changed to Ductile iron and cost is updated.

Table 3-3, Item 05-26: Material Listed as Grey Iron, Sand casting. But the actual material is a Ductile Iron sand casting. If Grey Iron was used in the cost analysis, then the machining cost will increase for ductile iron. There is also a small premium for the raw material over grey iron.

> **EPA's Response:** Same response as above.

Table 3-3, Item 04-20: Material Listed as Grey Iron, Sand casting. But the actual material is a Ductile Iron sand casting. If Grey Iron was used in the cost analysis, then the machining cost will increase for ductile iron. There is also a small premium for the raw material over grey iron.

> **EPA's Response:** Same response as above.

5.1.4 Editorial Comments

Executive Summary, Para 2: "In contrast to comparable cost analyses done in the past, which rely heavily on supplier price quotes for key components": This statement should specifically reference the ICCT and NREL Reports.

EPA's Response: ICCT and NREL papers were added as references to the report.

Section 1.A, Para 2: TMC: 'The TMC does not include OEM Indirect Manufacturing Costs (e.g. Corporate Overhead, SG&A, R&D, Tooling, etc.). Additional details on analysis boundary assumptions and cost factors are covered below in Section 1.D.'

Should read that TMC does include OEM Indirect Manufacturing Costs to be consistent with all other statements of TMC (page 5/ para-2; page 15/ para 1 & para 3, etc. are all correct).

EPA's Response: OEM indirect manufacturing costs were not included in the cost results provided. The reviewer might be confused with the reference to OEM direct manufacturing cost in the mentioned instance.

Attribute and Cost Summary Overview Tables: 'Rocker arm rod' should be 'Rocker Shaft' to match both item number and sub-subsystem.

EPA's Response: Corrected in all instances applicable.

Attribute and Cost Summary Overview Tables: Suggest that both TDMC and it's resultant value be bolded- to make clear that it is a sum of the values above it. This should also be done for TIMC. Doing this, would match why TMC and its' value are already bolded. I would do this for all the other tables too.

EPA's Response: Corrected in all instances applicable.

Table 6-2, Oil Control Module: As mentioned previously, EEVO is a different technology. This actuation is to provide engine braking, or compression release. Secondly, there is no pressure relief valve in the Baseline brake design. The embossment referenced is for the detent control valve.

EPA's Response: Corrected comments in mentioned instance to reflect compression release braking rather than EEVO.

Table 6-2, Oil Control Module: 'CDA Module has 4 Mounting Blocks compared to just 2 in baseline. In addition to 2 brake OCVs, CDA module has 4 CDA OCVs'.

The CDA system must have 6 CDA OCVs to enable 6 cylinder control, as defined elsewhere in the system description (Table 4-1 Key Attributes #3; Table 4-2, Item 06-37= 4 mounting blocks, with 2 Braking OCVs and 6 CDA OCVs, etc...)

EPA's Response: CDA OCV mounting block can station 2 OCVs and hence 4 would be sufficient for 8 OCVs (6 CDA OCVs and 2 brake OCVs). In contrast, baseline OCV can only station one OCV.

Section 7, Para 3: "Eaton's engine braking system can control individual cylinders ". This does not seem feasible with only the two Brake OCVs allowed in the BOM. If it was intended to say the CDA system can control 6 cylinders, then that is correct and then 'engine braking' should be corrected to ' CDA'.

Other combinations of the brake and CDA OCVs to enable both individual cylinder control of both CDA and braking would require additional components or more complex rocker shaft drilling that were not identified in the BOM or the previous noted functional requirements.

EPA's Response: Corrected to represent CDA for all 6 cylinders in final report.

Table 6-1: Should specify that this comparison is for the 15L. It does not apply to the L9 system.

EPA's Response: Corrected.

Executive Summary, Para after Figure 0-2: Reference to other OEs that use shrunk bearings is true, but the Daimler and PACCAR MX11 examples are DOHC, so the rocker arm loads are distributed over separate cams when compared to the Cummins X15 SOHC example. The ability of the cam journal size to be reduced, is a function of the amount of loads imparted to the cam through the rocker arm system. Here again, the Daimler and PACCAR examples only have intake and exhaust valve spring loads, but both these systems have very small rocker ratios because the valves are very close to their perspective rocker shafts. The X15 is a diamond pattern, where the intake rocker arm has a relatively large rocker ratio, and hence imparts more load onto the cam journal.

Volvo is a better comparison, as it is SOHC and is also a diamond pattern with larger rocker ratios. It also have injector pump rocker arms in three positions, that increase the overall load on the cam journal.

The cam journal load capability is also a function of the relative speed of the journal bearing, so as to maintain a hydrodynamic film to manage this load. This however, requires well fitting shaft to bore to prevent excessive leakage, and a subsequent loss of the oil film. Therefore, as smaller journal hole, would require alignment and a line-boring through the length of the entire cylinder head. This is a requirement for systems even with split bearings, but they may have different tolerance requirements.

Therefore, I would be careful not to assume too much cost reduction from the elimination of the bearings, as there may be additional costs to controlling the line-boring when there are no bearings. The other valve train relations first mentioned above need to be more broadly understood and compared.

EPA's Response: The engine examples provided included DOHC engines (Daimler, MX11) which was perhaps a bit misleading.

More relevant examples include the Volvo D13, Ford Ecotorq and the MAN D2676 (International). These are all SOHC engines with split bearing caps that would not require the additional bearing journal components for the FlexValve assembled camshaft.

These type of engines with cast iron cylinder heads are typically all line bored with bearing shells fitted, which is no different to the ISX 15 engine. There is no additional requirement for the camshaft bearings when applying the FlexValve system when compared to the base engine for these types of applications, therefore the cost reduction for not requiring these additional bearing components when compared to the feed through design of the ISX 15 is valid.

Table 0-2, Oil Control Module: Since there are 4 OCV modules, shouldn't the Qty column have '4' to match the note above the table? I understand that the unit cost is blended, but this would more clear. Perhaps add a '*' note to the Unit cost cell to refer to the blended cost in Table 4-2.

EPA's Response: As there are 4 Mounting blocks and 6 OCVs, unit cost doesn't make sense for this particular item.

Table 0-6: This assessment compares the cost estimate of CDA vs LIVC, but in this case the directly supported camshaft is used. However, it could be misconstrued that this camshaft was also part of the CDA configuration. As I did not see any reference to this, and there was no additional cost savings represented with this configuration with CDA, please add a note to the Table 0-5 note: '(directly supported camshaft design- for LIVC system only)'.

> **EPA's Response:** Directly supported camshaft doesn't change the cost estimate of CDA valvetrain.

5.2 Comments Submitted by Dr. James E. McCarthy

5.2.1 Summary Comments

The cost analysis was well done. It was good to include the baseline configuration of the valvetrain and the engine brake. This is particularly important since the addition of new technologies is not additive; rather, it is a system integration tasks -- (1) system solutions for CDA and Engine braking and (2) systems solution for LIVC and engine braking. I agree with the analysis for looking at the system costs and the delta in between.

> **EPA's Response:** Yes, baseline configurations also help us understand how these new technologies might effect adjacent engine systems like Cylinder Head, Gear train and Electrical harness.

The detailed bill of material was well done for the baseline, CDA/Brake and LIVC/Brake and the manufacturing cost of each item along with the assembly.

> **EPA's Response:** Thank you!

5.2.2 Technical Comments

Summary: I agree that the cost comparison is relative to mature production as opposed to the cost at production inception (or first year). Very good basis for comparison.

> **EPA's Response:** Yes, the purpose of the cost analysis was not to evaluate what these new valvetrain technologies would cost at production inception, but rather to understand how competitive these component technologies could be in the long-term compared to their existing baseline counterparts, evaluated under the same boundary conditions.

Tables 3-1, 4-1 & 5-1: The X15 cost analysis of $689.15 (Table 3-1) for the Baseline Valvetrain/Brake vs. for the CDA/Brake Cost of $900.35 (Table 4-1 and LIVC/Brake cost of 964.32 (Table 5-1) using 2019/2020 cost elements seems appropriate for mature production volumes. These values are also in Table 0-4 where the CDA/Brake delta is $211.20) and the LIVC/Brake delta is $275.16. These numbers look like the correct order of magnitude.

> **EPA's Response:** The cost numbers were updated based on comments from other reviewers. Nevertheless, the incremental cost numbers remain more or less same as mentioned here.

Tables 3-1, 4-1 & 5-1: 1st suggestion for above comment-It is worth noting that the CDA/Brake package averages to $150.06 per cylinder. This combined features of CDA & Engine Brake is within expectations. The baseline brake averages to $114.86 per cylinder leaving a delta of $35.20 for CDA with a system approach on a Type III valvetrain. Suggestion: many people in the industry look at both the system cost and cost per cylinder, so it may be worthwhile to pull out these per cylinder costs in the final report. This is especially important for customers who choose to use CDA on less than all cylinders while an engine brake is put on all cylinders.

EPA's Response: Cost per cylinder value added to all tables in Executive summary section.

Tables 3-1, 4-1 & 5-1: 2nd suggestion for above comment-I recommend to include another CDA/Brake variant that contains only 4 cylinders worth of CDA instead of 6 cylinders (see next comment below for additional details). This configuration (4 cyl. CDA and 6 cyl. Engine Brake) is a feasible implementation of CDA/Brake and the attractiveness of it is that it should lower the delta (less than $211.20) for OEM's that don't require all 6 cylinders worth of CDA to obtain the low load exhaust thermal management and fuel economy benefit.

Note for LIVC, the same scenario does not apply as all intake valves needs to have the same profile to obtain the desired result.

These numbers for LIVC are within the cost that I would expect for these system cost assessments.

EPA's Response: Cost per cylinder value added to all tables in Executive summary section.

Table 4-2 & 4-3: For the CDA cost analysis, it seems reasonable to quote three different scenarios based upon the number of cylinders with CDA. The current study assumes that all 6 cylinders are equiped with CDA (Table 4-2 item 37 for 6 OCV's on the X15 and Table 4-3 item 20 for 6 OCV's on the L9), which is the preferred configuration. This is the preferred configuration (as well as the most cost) as it allows any combintation of cylinder deactivation in addition to "full engine CDA" (eliminates convective heat transfer during vehicle coast, or downhill operation, as well as "no load operation" in order to keep the aftertreatment system hot).

However, an OEM may consider one of the two scenarios below (scenario A or B) if cost and/or service is an issue:

EPA's Response: I have provided cost per cylinder values for all 3 valvetrain technologies to be able to estimate cost of custom scenarios. Future durability and emission compliance regulations would restrict custom CDA installation and requires it to be installed in all cylinders. Hence not included in the Report.

Table 4-2 & 4-3: Scenario (A) for above comment -- Recommend to add this to the report
An OEM may consider this additional scenario if **cost and/or service** accessibility is an issue:
Scenario (A) CDA on cylinders 1-4 which enables half engine cylinder deactivation (cylinders 1,2,3) as well as cylinders four cylinders firing (deactivate cylinders 3 & 4). It may be worth noticing that the CDA/Brake on cylinders 1-4 is preferred as opposed to cylinder 3-6 as these are the easiest cylinders to service on the vehicle as cylinders 5 & 6 are the furthest away from the mechanic and typically constrained by the vehicle fire wall. This scenario is desirable to provide options to avoid NVH issues: Half engine CDA (deactivate cylinders 1-3) has a 1.5 dominate order for vibration while two cylinders firing (deactivate cylinder 3&4) is 1st order. Since the dominate orders are different, this give the OEM the opportunity for two options to switch between to avoid resonant frequecies on the vehicle. The downside is that full engine CDA for coast is not

available; however, either CDA on cylinders 1-4 or half engine CDA during "no load operation" will still provide ample benefit if this is chosen.

The cost structure for Scenario (A) would be **Two Cylinders of Baseline Valvetrain Hardware** and **Four Cylinders of CDA/Brake Hardware** (i.e., 1/3 cost of Baseline and 2/3 cost of CDA-Brake Hardware).

I recommend to add this variant to the report as it has a good cost-benefit trade-off.

> **EPA's Response:** Same response as above.

Table 4-2 & 4-3: Scenario (B) for above comment -- recommend to comment on this in the report, but not add costing for this option.

A more complex scenario could be a 5 cylinder CDA equipped engine; however, this is less attractive than the existing report with all cylinders equipped with CDA or Scenario A which four cylinders equipped with CDA.

Scenario (B) includes CDA on cylinders 1-5 as this allows for half engine CDA (cylinder 1,2,3), four cylinders firing (deactivate cylinders 3 & 4) and two cylinders firing (fire cylinders 1 & 6 while cylinder 2-5 are deactivated). This scenario allows for both two- and four-cylinders firing have the same dominant order of vibration -- Two cylinders firing is best for stay hot while Four cylinders firing is preferred above 2 bar BMEP. So, the authors could site this option; however, it is likely not worthwhile to include in the report while scenario A would be worth to include. The only real advantage of this scenario if for service related issues as cylinder 6 is typically under the fire wall of the vehicle and difficult to access.

The cost structure for this scenario would be One Cylinders of Baseline Valvetrain Hardware and Five Cylinders of CDA/Brake Hardware (i.e., 1/6 cost of Baseline and 5/6 cost of CDA-Brake Hardware).

> **EPA's Response:** Same response as above.

Table 6-2 & 4-2: Is there a typo for the number of OCV's for CDA/Brake configuration in Table 6-2 (Shows 4 OCV's on page 48)? The baseline should include 6 OCV's (see Table 4-2 item 37 on page 36). The CDA design has 4 OCV Mountings while it has 6 OCV's. Seems that the cost in Table 6-2 should have 6 OCV's instead of 4 OCV's. See the comment on Table 6-2 as it states 4 mounting blocks (this is correct) and only 4 CDA OCV's (should be 6). Please verify that the cost was captured correctly.

> **EPA's Response:** CDA OCV mounting block can station 2 OCVs and hence 4 would be sufficient for 8 OCVs (6 CDA OCVs and 2 brake OCVs).

Table 0-8: The L9 cost analysis of $516.70 (Table 0-8) for the Baseline Valvetrain vs. the CDA Valvetrain of $669.18 having a cost delta of $152.89 using 2019/2020 cost elements seems appropriate for mature volumes.

Consistent with the comment on the X15, it is worth noting this also on a per cylinder basis -- this comes out to $111.53 per cylinder worth of CDA which is within expectations for a Type V valvetrain.

Similar to the comment on the X15 for Scenario (A), it would be interesting to quote the cost for 4 cylinders of CDA and 2 cylinders of the baseline valvetrain for OEM's interested in fuel economy and exhaust thermal management at low load as this cost delta would be less than the $152.49. The L9 and/or B6.7 would have service issues where cylinders 5 & 6 are close to the fire wall on the vehicle where serviceability could be improved by installing CDA on only the first four cylinders. Plus, there would be a cost savings for the less cylinders with CDA.

These numbers are within the cost that I would expect for these system cost assessments.

> **EPA's Response:** I have provided cost per cylinder values for all 3 valvetrain technologies to be able to estimate cost of custom scenarios. Future durability and emission compliance regulations would restrict custom CDA installation and requires it to be installed in all cylinders. Hence not included in the Report.

Section 3, Phase 4.3 and Section 1.D: Is the cost for the 6.7L the same as the 9L? The dialog on Page 18 under phase 4.3 would imply this is true. However, the conclusions only site the 9L. If the author is stating that the 9L is used for costing while 6.7L is also a type V valvetrain that is representative of the L9, then that is valuable and should be cited that way. Please correct the wording if this is the intention. Page 19 cites many other engines and since these others are not cited relative to the X15 and L9, I am assuming that the L9 and B6.7 valvetrain costs are identical. If this is not true, then the wording should be adjusted. Additionally, Page 18 refers to a 6.7L engine while page 19 cites two different 6.7L engines -- Cummins B6.7 and Ford Powertroke 6.7 which do not have the same valvetrains -- the Cummins B6.7 is an inline 6 cylinder while the Ford Powerstroke 6.7L is a V8, so these are very different engines. I do not believe that the L9 valvetrain cost would be reflective of the Ford Powerstroke 6.7L; however, it is possible that the delta from CDA to the baseline could be reflective.

I am confident that the authors are referring to the B6.7L in this context while it is worth clearing that up and stating it as the case. Table 3-2 on page 30 clears this up as it cites that the B6.7 shares the same components as the L9.

> **EPA's Response:** It is assumed that 9L and 6.7L engines use same valvetrain components. Hence the cost of valvetrain for Cummins L9 and B6.7 are estimated to be same. Report is updated to clarify this further in mentioned instance.

Section 3, Phase 4.3 and Section 1.D: Recommendation to call out the L9 specifically instead of referencing the B6.7 as the same part.

It is worth noting that the L9 is likely to have higher valvetrain loads than the B6.7L. Although it is possible to create a CDA device for the L9 and use it for the B6.7L, the B6.7L will not need to hold up to the same loads as seen on the L9. In order words, the B6.7L deactivating device may be over-designed in this case. My recommendation is that the cost study calls out the L9 as the study and references that a simlar device, yet different device, could be used for the same type of engines such as the B6.7L. This would make the report clearer.

> **EPA's Response:** Comment regarding commonality between Cummins L9 and B6.7 is provided before Table 4-3 in the Report.

Section 3, Phase 4.3 and Section 1.D: Clarification on L9 vs. B6.7.

I recommend that the authors include a picture of the hydraulic roller lifter of the L9 in the report and show (with the existing picture in the document) that it can become a deactivating roller lifter for CDA. I would also like to provide clarification of the L9 vs B6.7. The L9 is a type V valvetrain with a hydraulic roller lifter. The B6.7L for the Dodge Ram Pickup (typically referred to as passenger car) also has a hydraulic roller lifter; however, the B6.7L for "commercial vehicle market" (~65% of the B volume) is a flat faced tappet (not a hydraulic roller lifter). The statement above remains true that a deactivating roller lifter could be installed on the L9 and if the same part is used for the B6.7L, it would be able to handle higher loads than needed (i.e., a little overdesigned). My recommendation is to clarify that the L9 hydraulic roller lifter could become a deactivating roller lifter for type V valvetrains; however, the direct reference to the B6.7L may need to be qualified better, if used at all. If the B6.7L is referenced, then it is worthwhile to cite the two configurations -- one with a hydraulic lifter and one with a flat faced tappet.

EPA's Response: Pictures of type V valvetrain (baseline and CDA) are added to the appendix. Comments in Phase 4.3 of Section 1.D are corrected to represent a comparison that is made between Cummins L9 and Cummins B6.7 engine valvetrains.

Section 2.A, Table 3-1, Table 6-2: Page 22 cites that the brake rocker arms allow engine braking by facilitating Early Exhaust Valve Opening (EEVO). This is technically true; however, early exhaust valve opening (EEVO) has other meanings in the engine/valvetrain industry. It would be worthwhile to cite that the brake rocker arm opens the exhaust valve near top dead center for compression release braking; thus, enabling engine braking as opposed to what EEVO is typically referred to as "heating up the exhaust aftertreatment system" that has an inherent fuel penalty associated with this function. The author could add comments that the exhaust valve opens early for brake gas exhaust recirculation (sometimes called "BGR" in the industry which is used to add cylinder pressure to the cylinder when the piston is near bottom dead center and allowing for more potential braking power when the exhaust valve opens at top dead center) followed by compression release near top dead center. I suggest removing EEVO and call it Engine Braking (compression release) instead.

EEVO is also cited on page 29 in Table 3-1 and page 47 in Table 6-2.

EPA's Response: Corrected comments in mentioned instances to reflect compression release braking rather than EEVO.

Figure 2-2: Technical Detail for Additional Consideration.

The present CDA setup requires one OCV per cylinder such that the OCV deactivates the intake and exhaust valve. The method in which the engine transitions from normal six cylinders firing to CDA is typically the following: an oil pressure signal is sent to the intake and exhaust deactivation devices following the intake event (or once the intake is in the latch restricted state) such that the next exhaust event is deactivated (and likewise the next intake event).

This is the baseline for the report and it is worth noting this function is commonly referred to as entering CDA with "high pressure trapping" although "high" is a relative term since it is a function of the intake manifold pressure. In this way, CDA can be entered with either "fresh charge trapping" or "combusted charge trapping." The different between "fresh" and "combusted" is where a fuel injection occurs after the last intake event or not. Both of these methods are commonly referred to as "high pressure trapping" events and it is worth noting this function in the report.

An alternative CDA method to "high pressure trapping" is provided below.

> **EPA's Response:** Yes, the present CDA hardware is only capable of "high pressure trapping". This is now explicitly described in the Report in Section 2.B where valvetrain technologies are introduced.

Figure 2-2: Optional addition for "low pressure trapping" call-out in the report.

An alternative to "high pressure trapping" is "low pressure trapping" that has been reported in the industry. In this method, the control strategy from normal six cylinders firing mode to CDA would enter CDA following the last exhaust event. This adds some complexity since the intake event typically opens slightly before the exhaust closes. In order to enable "low pressure trapping," one method would be to double the number of OCV's such that there is independent control of the intake and exhaust events for each cylinder. Likewise, the oil passages in the rocker arms would need to be separated. There are other ways to do "low pressure trapping;" however, this may be considered within the cost study of this project for ballpark numbers.

It may be worth noting that "low pressure trapping" is likely to have a higher complexity for the number of OCV's and oil passages while a system solution to commonize "like functions" is also possible. If adding more OCV's for independent control of the intake and exhaust are used, then it would be challenging to incorporate the OCV's and oil passages for the engine braking function.
As long as "high pressure trapping" is noted in the report, providing details on "low pressure trapping" is optional.

My recommendation is to clarify the the CDA system is considered "high pressure trapping" and I don't think that it is worth adding details to cost a "low pressure trapping" system. However, the authors could add a comment that the "low pressure trapping" CDA system is likely more complex.

> **EPA's Response:** Yes, "low-pressure trapping" would have higher complexity in number of OCVs and oil passages and is quite challenging to incorporate. Relevant text is added to Section 2.B of the final report.

Section 1.A, Para 4 and Figure 7-1: It would be useful to cite the physics of exhaust temperature increase in the report and how these technologies can increase exhaust temperature. Specifically, exhaust temperature in this context is the turbine outlet temperature. Exhaust temperature increase is driven by lowering the air fuel ratio below a critical number. Typically, lowering the air fuel ratio below 45:1 has the largest impact on air fuel ratio. Half engine CDA can cut the air fuel ratio in half. For LIVC, the effect on air fuel ratio is typically less while LIVC will have more benefit in exhaust temperature increase when the starting air fuel ratio is near or below 45:1. It seems that LIVC would be a larger play at medium to high load where the air fuel ratios are in this range. At low load, LIVC seems to have a lesser effect as normal air fuel ratios can be in the 80:1 to 120:1 range.

The summary on page 50 suggests that LIVC can increase exhaust temperature by 100C (also stated on page 13). It may be worth citing that this is due to the very short duration of the intake event as shown in Figure 7-1. The authors should specify as to what the operating mode is for this increase. I believe that this has to be medium or high load (not low load). Please add some qualifying statements here. The way it is written, one could assume that this is light load as it follows the CDA statement at light load. The next paragraph also supports LIVC for low load; however, I don't believe that 100C increase is possible unless the intake event is very short. This is only possible if it can substantially drop the air fuel ratio below 45:1. Figure 7-1 shows a small intake event for low load. Is there data that supports this level of exhaust temperature increase? If so, it would be worth adding to the report or at least a journal article reference for that 100C temperature increase.

I could not find data that supports this type of number by searching the FlexValve system on the internet. If there is a journal article, it would be good to cite that reference.

> **EPA's Response:** The example provided in figure 7.1 is a bit missleading as it is an EIVC strategy and not LIVC which is the subject of the report. The FlexValve system is able to provide many different families of valve lift curves, depending on the design and the interaction of the two different cam lift profiles.
> An alternative figure has been provided which shows how the FlexValve system can provide benefits across the operating range with the LIVC strategy that should avoid any confusion.
> Reference to exhaust temperature increase in LIVC valvetrain and load condition is provided in Section 1.A (para 4).

Table 7-1: The FlexValve LIVC for low load exhaust thermal management is really Early Intake Valve Closing (EIVC) as opposed to Late Intake Valve Closing (LIVC). Perhaps this is just a trade name for LIVC. It seems that a more representative name for the FlexValve system in this report is Variable Intake Valve Closing (VIVC) or Continuously Variable Intake Valve Closing (CVIVC). My assessment is that the FlexValve LIVC for continuously variable IVC includes EIVC, normal valve operation and possibly LIVC (with perhaps a valve overlift condition). Further clarification is required in the report as noted below.

> **EPA's Response:** Same response as above.

Table 7-1: Follow up question and comment for FlexValve LIVC.

A true LIVC option is not obvious from the description in the report. Miller cycle operation is typically associated with LIVC operation; however, the latest valve closing is associated with peak torque and max power operation in Figure 7-1. Question -- does the maximum intake valve lift for peak torque/max power exceed that of the baseline valvetrain. Many valvetrains are constrained by maximum lift and many LIVC systems can extend lift without overlifting the valve. If this system has higher lift than the baseline, then it should be noted. If it doesn't, then it is hard to envision that this system offers later Intake Valve Closing than the baseline system. So, LIVC is not associated with Miller cycle while it appears that EIVC is associated with low load thermal management. This should probably be made clearer in the report. The technology shown in Figure 7-1 may be better represented as variable intake valve closing instead of late intake valve closing. Additionally, I looked up the FlexValve system on the internet (https://www.mechadyne-int.com/app/uploads/2016/03/FlexValve-Handout.pdf) and it does not claim LIVC, rather continuously variable intake lift, but not LIVC (meaning later than normal closing).

> **EPA's Response:** Same response as above.

It may be useful to cite the timing accuracy of cylinder-to-cylinder intake valve opening and closing accuracy with a cam-in-cam design relative to a production fixed ground cam. The timing accuracies should be cited relative to TDC for each cylinder. My experiences are that a cam-in-cam technology is difficult to reproduce the timing accuracies as a fixed ground cam (cam timing opening/closing and cylinder to cylinder variation). For comparison, the baseline valvetrains have a fixed ground cam with tight tolerance. The CDA technology maintains this accuracy when the valves are operating while when the valves are deactivated, timing accuracy does not apply.

It may be possible that the timing of the intake valve opening is accurate compared to a fixed ground cam if the only aspects being altered is the closing event. A comment is warranted in the report as to the accuracy at which the FlexValve system closes the intake valve relative to a fix ground cam.

My recommendation is that the authors include a dialog to how the FlexValve is altering the valve profile timing and cylinder to cylinder accuracy may be worthwhile. This is important as it relates to cost-benefit trade-offs because if tighter timing is required, the cost will increase. I have been part of a project where this was assessed and improving the tolerances on the cam-to-cam timing resulted in significant cost increase. Since this is a costing report, is this detail included as part of the "benefit" document (i.e., cost-benefit of each technology). My recommendation for the report is to cite the relative comparison of cam-to-cam timing versus a fixed ground cam such that the reader understands the baseline.

> **EPA's Response:** The assembling processes for the FlexValve camshaft yields similar accuracy to the grinding of solid camshafts. The valve opening timing with the FlexValve LIVC is fixed, and as such has good accuracy.
>
> Due to the good accuracy of the assembly process, the cylinder to cylinder variation is also equivalent. The valve closing timing accuracy is dictated by the control system, which is typically in the range of +/-1° (crank) when holding a fixed position.
>
> The benefit of the FlexValve system is that it allows optimization of the airflow through the cylinder across the engine range, compared to a fixed or a switching system that is only optimal at a few operating points.
>
> Exhaust thermal management is not a strategy that requires precise control of the valve closing, therefore it should not be necessary to try and achieve a higher accuracy of the valve closing timing, and in our view this is not something that needs to be discussed in the report.

5.3 Comments Submitted by Dr. Greg Shaver

5.3.1 Technical Comments

I would suggest adding explanations in the report to clearly indicate why the Eaton CDA-capable valvetrain system was specifically considered over other systems, what evidence suggests it is representative, and what other CDA-enabling strategies exist, and what other companies are likely to provide them for diesel CDA.

> **EPA's Response:** Eaton system is picked due to the familiarity and accessibility at the time of project proposal.

Same question as above, but this time specific to Mechadyne's FlexValve module.

EPA's Response: Mechadyne's LIVC offers flexibility, not evident in other heavy-duty suppliers at the time of project proposal.

It would be interesting to see the cost for a valvetrain that would enable CDA + LIVC on the activated cylinders. Purdue research also shows a lot of merit for iEGR, by itself, as well as when implemented on the activated cylinders during CDA. As such it would be interesting to understand the cost of those variants, as well.

EPA's Response: iEGR would increase the soot load on DPF. As future aftertreatment systems focus on low NOx and keeping DPF same, this technology might not be feasible or not in scope of this project.

Section 1.A, Para 4: iEGR also has a lot of merit for fuel-saving aftertreatment stay-warm operation. iEGR and LIVC also each have merit when implemented on the activated cylinders during CDA operation. I recommend those technologies be costed-out as well.

EPA's Response: Same response as above.

paragraph 4: "...increases of up to 60°C …" Increases can be higher than this.

EPA's Response: Comment updated with reference.

Figure 1-2: It is not clear if/how every single one of the steps in this figure was completed.

EPA's Response: Section 1.C provides a detailed explanation highlighting various steps of the cost methodology. In addition, Figure 8-7 and Figure 8-8 show detailed should-costing template and underlying assumptions.

Figure 2-2: More information about how these functions would be helpful.

EPA's Response: Additional design and functional attributes added to the report.

Section 7, Para 3: A more thorough statement of benefits for CDA can be provided. See recent Purdue/Eaton and SWRI/Eaton webinars, for instance. I can also provide peer-reviewed paper & presentation CDA references if that is helpful.

EPA's Response: Comments regarding engine-out temperature provided with references.

APPENDIX A

RESUMES OF SELECTED REVIEWERS

ROBB JANAK

Jacobs Vehicle Systems

During his time at Jacobs Vehicle Systems, Robb has accumulated over 25 years of engine brake, valve-train and VVA development experience. Robb's career at Jacobs began in manufacturing support. He went on to hold positions in production and product support utilizing Design for Six Sigma and leading Kaizens in Lean Manufacturing. Robb went on to manage several product development groups and Jacobs' engineering laboratory where he had responsibility for launching numerous products for OEMs globally. As the Director of New Technology, Robb's objective is to develop technology to meet customers' future needs. During his career, Robb has contributed to over twelve US and international patents involving valve train components, systems and processes. He holds a Bachelor of Science in Mechanical Engineering and Materials Science from the University of Connecticut

LinkedIn Profile

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JAMES E. McCARTHY, JR.

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PROFESSIONAL OBJECTIVE

Executive leadership in Energy for conserving fossil fuels and reducing emissions by creating organic growth solutions through innovation, product development, intellectual property and publications. Growth objectives and trust are augmented through data driven evidence to support technology solutions and continued relationships with Partners, Government, Industry, Academia, Research Laboratories and Customers.

PASSION FOR DEVELOPING PEOPLE

Mentoring new engineers to be successful in promoting their works in public conferences along with promoting intellectual property via patents has been a passion of mine. I have worked with more than thirty engineers to help them obtain their first journal publication. Additionally, I mentored three engineers that received best oral presentation at SAE and managed two engineers who received engineer of the year at Eaton.

EMPLOYMENT

Eaton Corporation, Galesburg, MI – **Chief Engineer** (2/2017 – present)

Responsible for vehicle market trend analysis, opportunity assessment and competitive technology assessment to guide the Eaton Vehicle Technologies and Innovation portfolio. Grew Eaton Intellectual Property Portfolio (Component and Systems) for Engine, Aftertreatment and Vehicle Powertrain. Key Accomplishments:

(1) Leader for data driven results to support the benefits of new technologies both internally and with customers / regulators.

(2) Led Diesel CDA over the years which has transpired into a business opportunity with IP protection for Eaton for simultaneously reducing both tailpipe NOx and CO_2 (greenhouse gas) emissions. Government regulators are promoting Diesel CDA for 2027 emissions while some customers may become early adopters in 2024.
- Led team to show path to solve NVH for diesel CDA trucks in 2019.

(3) System integration of advanced diesel and aftertreatment with cylinder deactivation, close coupled catalysts and 48V EGR pump.

(4) Principle Eaton Investigator during 7-year research program with Purdue University and Cummins for Advanced Engine Combustion and Aftertreatment Using Variable Valve Actuation. This investigation helped shape engine technologies that are most viable for upcoming emissions regulations while preserving/improving fuel economy.

(5) Built key relationships with Government, Industry, Academia and Reporters showing that Eaton is a trusted advisor for existing and new technologies.

(6) Leader in Innovation and Intellectual Property for Engine and Vehicle Powertrain systems.

Eaton Corporation, Marshall, MI – **Engineering Manager** (2/2011 – 1/2017)

Led engineering team for advanced valvetrain ideation/design/development/product launch for passenger car and heavy-duty markets including gasoline, diesel and natural gas products. Major contributions include:

(1) Led product win for first Roller Follower Hydraulic Lash Adjustor (RF-HLA) in the North America on the Cummins ISB 6.7L (Full SOP Dec. 17, 2018).
(2) Managed the engineering team for Cylinder Deactivation (CDA) on the GM high feature V6 engine from product inception, win, development, validation and launch (June 2015). Leadership recognized the launch as one of the best this decade.
(3) Developed & Promoted Variable Valve Actuation (including Cylinder Deactivation) for diesel engine through internal/customer testing combined with journal paper publications.
(4) Mentored direct reports who achieved highest honors: (i) Best Presentation Awards at three separate SAE conferences (2012, 2013 and 2015) where all three engineers were first time authors and (ii) Eaton Engineer of the Year Awards (2012, 2015).
(5) Managed the engineering team thru the final design validation, program launch and market success for Variable Valve Lift (VVL) on the GM Chevrolet Impala and Malibu.
(6) Managed the engineering team thru product "win," design, design validation, PPAP and product launch for cylinder deactivation which launched flawlessly in June 2015.
(7) Developed programs for multiple heavy-duty diesel and natural gas customers for hydraulic lash adjustment and variable valve actuation.
(8) Developed a research consortium partnership with Cummins and Purdue for next generation VVA developed with simulation and camless engine testing on the ISB 6.7L with multiple journal and conference publications showing the benefits of VVA.
(9) Intellectual Property Chair for Global Valvetrain business. Significantly grew IP portfolio of VVA thru strategic VVA patent landscape analyses along with level 1-4 patents.
(10) Key contributor and author of the year 2050 National Petroleum Council technology assessment.

Eaton Corporation, Southfield, MI – **Engineering Manager** (7/2003 – 2/2011)

Previous positions -- Chief Engineer, Senior Technical Specialist & Principle Engineer

Engineering expertise focused in areas of diesel engine emissions reduction, aftertreatment solutions, new program ideation, fuel dosing systems, vehicle system integration and exhaust energy recovery systems. Major contributions include:

(1) Managed On/Off-highway aftertreatment customer programs, systems integration, aftertreatment sizing and design teams. Negotiated multiple multi-million-dollar contracts.
(2) Demonstrated a "world's first" in aftertreatment diesel engine emissions for a Lean NOx Trap system meeting both 2010 on-highway and 2014 final tier 4 emission regulations.
(3) Recognized innovator and leader for Eaton's Aftertreatment program (fuel reformer, LNT, DPF and SCR catalysts) from the initial concept stage through product development.
(4) Recognized leader for bringing new capabilities to Eaton – including fuel dosing systems, spray characterization, simulation fundamentals, measurement equipment and test facilities.
(5) Led technical development of Eaton's initial fuel dosing systems including system development, fuel spray characterization and exhaust tailpipe fuel spray simulation.
(6) Demonstrated technical leader of developing opportunities with Thermoelectric & Quantum Well devices for harvesting wasted heat energy into electrical energy.
(7) Chaired Intellectual Property for Global Valvetrain business. Eaton sold the IP portfolio to Pure Power Technologies. This has been recently sold again to Ricardo.

Detroit Diesel Corporation, Detroit, MI – **Staff Technology Engineer** (3/1995 – 6/2003)

Engineering expertise focused in areas of fuel & air system development, engine controls & calibration, emissions reduction & testing along with spray measurement & characterization. Major contributions included:

(1) Recognized innovator and technical leader for development and integration of a common rail fuel system on a heavy-duty diesel engine.

(2) Led integration of designed experiments methodology in engine development that resulted in statistical models for engine performance and emissions parameters.

(3) Recognized innovator and leader of multiple heavy-duty diesel engine emission reduction programs required to meet U.S. transient and steady state emissions including:

(a) Internal research program focused on U.S. 2007 emission levels using rapid prototype control models and prototype engine hardware.

(b) Government sponsored program focused on optimizing the engine design and control system to demonstrate fifty percent thermal efficiency at U.S. 2007 emission levels.

(c) Internal research program focused on U.S. 2002 emission levels using a systems approach with a common rail fuel system, advanced air system controls and combustion optimizing in calendar years 1999-2000 as well as another program using advanced unit injectors combined with internal/external exhaust gas recirculation in calendar year 1997.

(d) Internal research program focused on developing a 3.0 g/hp-hr NOx engine for the purpose of an industry round robin emission study using multiple diesel fuel blends.

University of Wisconsin-Madison, Adjunct Professor (10/2016 – present)

Teach professionals for continuing education how modern engine Valvetrain systems are designed and its role for internal combustion engine performance and emissions.

EDUCATION

Purdue University, West Lafayette, IN 47907

Doctor of Philosophy in Mechanical Engineering, May 1995

Dissertation: “Paint Transfer in Electrostatics Air Sprays”

Master of Science in Mechanical Engineering, December 1991

Thesis: “Basic Studies on Spray Coating: Drop Rebound from a Small Workpiece with a Conventional Air Applicator,”

Bachelor of Science in Mechanical Engineering, May 1990

OUTSTANDING TECHNICAL ACHIEVEMENT AWARDS

- 2020 Purdue University: Outstanding Mechanical Engineering Career Award
- 2020 Dossier Career Article by SAE Update

- 2019 Best Presentation Award at SAE Brazil
- 2018 John Johnson Award at SAE for Best Diesel Paper
- 2011 W. R. Marshall Award at the Institute for Liquid Atomization and Spraying Systems
- 2009 SAE Excellence in Oral Presentation Award -- 2009 Commercial Vehicle Conference
- Eaton Vehicle Group 2008-2009
  - Aftertreatment System Durability and Advanced Control System
  - Pressure Swirl Atomizer for Aftertreatment Dosing with Integrated Safety Manifold
- Eaton Truck Group, 2007-2008
  - Aftertreatment System Design and Integration for an Off-Highway Front End Loader

TEAM ACHIEVEMENT AWARDS

- Mentored three engineers to achieve SAE Excellence in Oral Presentation (also co-authored on first two)
  - Daniel Trudell, SAE Powertrain Fuels and Lubricants, Sept. 18-20, 2012.
  - Andrei Radulescu, SAE World Congress, April 16-18, 2013.
  - Eric Yankovic, SAE Commercial Vehicle Congress, Oct. 6-8, 2015.
- Managed valvetrain team that yielded two Engineer of the Year Award Winners for Eaton in Valvetrain: Austin Zurface 2012 and Andrei Radulescu 2015.

INFLUENCING INDUSTRY, GOVERNMENT AND ACADEMIA

1. ***Dossier Article on Jim McCarthy of Eaton,*** SAE Update Magazine Feb. 2020, pages 16-19.
2. ***Technical White Paper to the Advisory Group on Vehicle Emission Standards under the European Commission***, "Simultaneous Reduction of NOx and CO_2 Emissions of HD Diesel Powertrains," James McCarthy, Jr and Milos Toulec, Jan. 16, 2020.
3. ***Invited Talk at SAE COMVEC 2019,*** "Simultaneous NOx and CO_2 Reduction for Meeting Future CARB Standards using a Heavy-Duty Diesel CDA-NVH Strategy," SAE COMVEC, Indianapolis, IN, Sept. 9th, 2019.
4. ***Invited Speaker and Panelist for SAE Brazil 2019,*** "Meeting Future Low-Load Emissions Using Cylinder Deactivation to Achieve Simultaneous NOx and CO_2 Reduction," SAE Brazil, Curitiba, Brazil, Sept. 4th, 2019.
5. ***Keynote Speaker at GAMC Emissions 2019 Conference,*** "Meeting Future Low Load Emissions Using Cylinder Deactivation and EGR Pumps to Achieve Simultaneous NOx and CO_2 Reduction," Livonia, MI, June 5th, 2019.
6. ***Invited Speaker for SwRI CHEDE VII*** *(Clean High Efficiency Diesel Engines)* ***Consortium,*** "Eaton NVH Assessment for Cummins X15 CDA at SwRI-CHEDE," San Antonio, Texas, Matt Pieczko and **James McCarthy, Jr.,** Mar. 6th, 2019.
7. ***Invited Speaker for Integer Emissions Summit Brazil 2019,*** "Simultaneous CO_2 and NOx Reduction for Medium & Heavy-Duty Diesel Engines using Cylinder Deactivation," Sao Paulo, Brazil, https://www.integer-research.com/conferences/ies-brazil-2019/, Feb. 12th, 2019.
8. ***Invited Speaker for Advanced Engine Crosscut Meeting at USCAR,*** "Simultaneous NOx and CO_2 Reduction Using Cylinder Deactivation for MD/HD Diesel Engines," Southfield, MI, Jan. 10th, 2019.
9. ***Keynote Speaker at GAMC Emissions 2018 Conference,*** "Exhaust Temperature Improvement Using Cylinder Deactivation for MD/HD Engines & Aftertreatment Temperature Challenge at Low Loads," Livonia, MI, May 24, 2018.

10. ***Invited Speaker for SwRI CHEDE VII** (Clean High Efficiency Diesel Engines)* ***Consortium,*** "Improving Diesel Fuel Economy and Emissions at Low Loads Using Cylinder Deactivation," San Antonio, Texas, Nov. 2, 2017.
11. ***Invited Speaker for 2017 Symposium,*** "Enabled Improved Vehicle Fuel Economy and Emissions," http://www.erc.wisc.edu/symposium2017.php, Engine Research Center, University of Wisconsin-Madison, June 14, 2017.
12. ***Valvetrain Development Workshop for Internal Combustion Engines***, Adjunct Professor for the University of Wisconsin-Madison, Oct. 18-20, 2016 and May 1-3, 2017.
13. ***Keynote Guest Speaker for Advanced Valvetrain***, Keynote to Faculty and Student (Undergraduate and Graduate) at Purdue University, Sept. 21 and 29, 2016.
14. ***Driving Automotive Innovation Conference,*** Invited Panelist, "**Cylinder Deactivation for Optimizing Conventional Engines**," http://www.theicct.org/events/driving-automotive-innovation, Senate Hart Building, Washington, D.C., Sept. 13, 2016.
15. ***SAE Technical Webinar*** Titled "**Next Generation Advanced Combustion/Aftertreatment**," Recording available at https://event.webcasts.com/starthere.jsp?ei=1109742, Chi Binh La [IAV], Dr. James McCarthy, Jr. [Eaton] and Dr. Ben Patel [Tenneco], Aug. 4, 2016.
16. ***Keynote Speaker at NAACEE Annual Conference*** Titled "**Valvetrain Fuel Economy Solutions**," Southfield, MI, April 16, 2013.
17. ***Technology & Maintenance Council (TMC) Invited Talk*** Titled "**The Future of Fuels for Heavy Trucks**," Featured Speaker at TMC Spring Meeting for Future Transportation Energy Sources for reporting Findings from the National Petroleum Councils 2012 Study: Advancing Technology for America's Transportation Future, Nashville, TN, March 12, 2013.
18. ***Advancing Technology for America's Transportation,*** Core Member for Writing Chapter 3: **Heavy Duty Vehicles Report** for the National Petroleum Council, Available at www.npc.org, Aug. 2012
19. ***VDV-Akademie-Seminar Invited Talk*** Titled "**Meeting Worldwide Emission Standards with Eaton's Urea-Free, Durability-Proven, Fuel-Efficient and Compact Aftertreatment System**" Cologne, Germany, June 16-17, 2010.

PRESS PUBLICATIONS

1. ***Transporte Mundial,*** **"Tecnologia que desativa cilindros pode fazer motor diesel ser mais econômico e menos poluente,"** By Marcos Villela, Diesel Cylinder Deactivation interview with James McCarthy, Jr., Available at: https://transportemundial.com.br/eaton-cda/, Apr. 23, 2019.
2. ***Engine Technology International,*** **"Intelligent Valvetrains: Lift Your Game"** By Chris Pickering, Diesel Cylinder Deactivation interview with James McCarthy, Jr., Available at: https://www.ukimediaevents.com/publication/56d7f3a8/46 (www.EngineTechnology International.com), pgs. 44-48, Jan. 2019.
3. ***Engine Technology International,*** **"Double Down: Advances in Cylinder Deactivation Ensure The Technology is Now More Applicable to Auto Makers than Ever Before"** By Lem Bingley, Diesel Cylinder Deactivation interview with James McCarthy, Jr., Available at: https://www.ukimediaevents.com/publication/d551a338/34 (www.EngineTechnology International.com), pgs. 32-36, Sept. 2018.
4. ***Heavy Duty Trucking, "Is Displacement on Demand Coming to Heavy-Duty Diesel Engines?"*** By Jack Roberts, Diesel Cylinder Deactivation Interview with James McCarthy, Jr., Available at: https://www.truckinginfo.com/313374/is-displacement-on-demand-coming-to-heavy-duty-diesel-engines?utm_source=email&utm_medium=enewsletter&utm_campaign=20180914-NL-HDT-

HeadlineNews-BOBCD180908002&omdt=NL-HDT-HeadlineNews&omid=1009647408, Sept. 13, 2018.

5. ***SAE Momentum Magazine,*** **"Eaton puts students under the conference spotlight,"** http://www.nxtbook.com/nxtbooks/sae/18MOMP11/index.php#/2, Pages 16-17, Nov. 2018.
6. ***Automotive News,*** **"Eaton bringing cylinder deactivation to diesels,"** http://www.autonews.com/article/20180731/OEM10/180809995/eaton-engine-cylinder-deactivation-diesel, July 31, 2018.
7. ***Detroit Free Press,*** **"Cutting-edge companies fighting over students hungry for challenge,"** https://www.freep.com/story/money/cars/2018/05/08/engineering-students-internships-competitive/575280002/, May 8, 2018.
8. ***DieselNet Summary of Two Eaton SAE Papers on Diesel CDA from SAE WCX 2018,*** https://dieselnet.com/newsletter/2018/04.php, April, 2018.
9. ***Motortrend,*** **"Eaton Diesel Cylinder-Shutoff,"** https://www.motortrend.com/news/13-tech-trends-worth-watching-2018-sae-world-congress/, April, 2018.
10. ***Diesel Progress North American,*** **"Cylinder Deactivation Coming to Diesels?,"** http://edition.pagesuite.com/html5/reader/production/default.aspx?pubname=&edid=a5d1ab62-cc55-4a6f-ac44-a0404ac9c25f, page 4, June, 2017.
11. ***Automotive Engineering,*** "**Pushing the ICE forward, gradually**" by Lindsay Brooke, Cylinder Deactivation interview with James McCarthy, Jr., pgs. 24-27, Available at: http://magazine.sae.org/16autp06/, Jun. 2, 2016,
12. ***Engine Technology International,*** **"Independent Variable"** By John Evans, Cam-Camless interview with James McCarthy, Jr. and Dale Stretch, Available at: http://viewer.zmags.com/publication/0b7ebb6c#/0b7ebb6c/1 (www.EngineTechnology International.com), pgs. 44-48, Jan. 2016.
13. ***SAE Off-Highway Featured Article,*** "**Saving Space**," based on work from Bret Armanini and James McCarthy, Jr., Available at: http://magazine.sae.org/11ofhd0310/, pgs. 9-12, Mar. 10, 2011.

COMMITTEE REPRESENTATION

- **2020 Panel Organizer: SAE Commercial Vehicle Powertrain Conference**
  - IC Engine/Aftertreatment Graduate Student Panel (3rd Annual):
    - Moderator: Tim Kroeger (Texas A&M) / Panelists: Miles Droege (Purdue), Vijay Sankar Anil (The Ohio State University) and George Koutsakis (University of Wisconsin-Madison)
    - Organizers: Truemner (AVL), Duffy (Caterpillar), McCarthy (Eaton)
- **2019 Panel Organizer: SAE Commercial Vehicle Powertrain Conference**
  - IC Engine/Aftertreatment Graduate Student Panel (2nd Annual):
    - Moderator: Dheeraj Gosala (Moderator-Cummins) / Panelists: Mrunal Joshi (Purdue), Luis Silva (Western Michigan University), Hunter Zhang (University of Alabama-Birmingham) and Jon Furlich (Michigan Technological University)
    - Organizers: Truemner (AVL), Goffe (PACCAR), McCarthy (Eaton)
- **2018 Panel Organizer: SAE Commercial Vehicle Powertrain Conference**
  - IC Engine/Aftertreament Graduate Student Panel (Inaugural Event):
    - Panelists: Meng Tang (Michigan Technological University), Flavio Chuahy (University of Wisconsin-Madison), Tim Kroeger (Texas A&M) and Dheeraj Gosala (Purdue University)

        - Organizers: Truemner (AVL), Goffe (PACCAR), McCarthy (Eaton)
- **2017 Panel Organizer: SAE Commercial Vehicle Powertrain Conference**
    - Organized Energy Conversion Panel
        - Moderator: Dr. Mihai Dorobantu (Eaton) / Panelists: Chris Gearhart (NREL), Stephan Tarnutzer (FEV), Lukas Walter (AVL)
        - Organizers: Nedelcu (PACCAR), McCarthy (Eaton)
- **2016 Powertrain Chair: SAE Commercial Vehicle Powertrain Conference**
    - Led Powertrain Section Including Technical Paper Review
    - Panel Discussion Titled "**Connectivity: Meeting Future Commercial Vehicle Powertrain Challenges**"
        - Moderator: Craig Savonen (Daimler) / Panelists: Mike Gerty (PACCAR), Tom Stoltz (Eaton), Dr. Patric Ouellette (Cummins Westport), Prof. Zongzuan Sun (Univ. of Minnesota)
        - Organizers: Gerty (PACCAR) and McCarthy (Eaton)
- **2015 Powertrain Co-Chair: SAE Commercial Vehicle Powertrain Conference**
    - Led Powertrain Section Including Technical Paper Review
    - Panel Discussion Titled "**Meeting Future Commercial Vehicle Powertrain Challenges Through Quality, Technology and Innovation**"
        - Moderator: Mike Gerty (PACCAR) / Panelists: John Cagney (WeiChai), Lukas Walter (AVL), Gerard DeVito (Eaton), Jay Deveny (AxleTech) and Ken Price (Umicore)
        - Organizers: Trumner (AVL) and McCarthy (Eaton)
- DOE 21st Century Truck Partnership (2018-present)
- Global Automotive Management Council (GAMC)
    - Board of Directors (2019-present)
    - Emissions Chair (2018-present) / Keynotes in 2018/19
- National Petroleum Council for Heavy Duty Trucks (2011-2013)
- Technical Expert for Reviewing Papers (2003-present)

TECHNICAL EXPERTISE

- Intellectual Property protection (IP Chair for Eaton Aftertreatement and Valvetrain)
    - Secured patent portfolio for Aftertreatment. Eaton sold the business and portfolio.
    - Create technical IP landscape for valvetrain and secured IP for product launches and development programs.
    - Managing IP portfolio for the Vehicle Group within the Vehicle, Technologies and Innovation organization.
- Mentor for clear/concise presentation skills
- University/Research collaboration to accelerate knowledge and direction for product development
    - Two-way collaboration: Eaton and University
    - Three-way collaboration: Eaton, Customer/Supplier and University
    - Larger consortiums
- Government relationships to align direction for product development

- EPA/CARB
- Conferences/Collaborations/Consortiums
- Certified Design for Six Sigma Green Belt, Dec. 2012
- Product Innovation, Development and Production Release
  - Innovation Workshops, Planning, RASIC
  - Product and System Design, DFMEA, DVP&R, FRACAS, Reliability Growth
- Variable Valve Actuation
  - VVA system design including variable valve lift, cylinder deactivation, hydraulic lash adjustment and camless/cam-camless
- Diesel Aftertreatment Systems
  - NOx Abatement Catalysts (SCR & NOx Adsorber Regeneration and Desulfation)
  - Aftertreatment Diesel Fuel Dosing
  - Fuel Reformer Catalysts, Diesel Particulate Filters
  - System Integration and Catalyst Canning, Exhaust Aftertreatment Sizing
  - Six Sigma Tools (DOE, QFD/House of Quality/Design Scorecards, FMEA, etc.)
  - Transient and Steady State Performance and Emission Testing
  - Exhaust Cooling Devices
- Exhaust Energy Recovery Systems Using Quantum Well and Thermoelectric Devices
- Advanced Engine Technology Development including:
  - Fuel Injection Systems (Common Rail and Unit Injection System)
  - Internal and External EGR Systems
  - Variable Nozzle Turbine (VNT) Turbocharger Systems
  - Advanced diesel engine calibrations for multiple engine OEM's
- Fuel Injection and Sprays Characterization
  - Characterization of Common Rail and Electronic Unit Injectors
  - Characterization of Electrostatic/Conventional Paint and Diesel Sprays
  - Phase Doppler Anemometry (PDA) Measurements for Paint and Diesel Sprays
  - Malvern Particle Sizer Measurements for Paint and Diesel Sprays
  - SETscan Optical Patternator for Diesel Sprays

PROFESSIONAL ORGANIZATIONS

SAE Commercial Vehicle Congress (Energy Conversion Panel Co-Chair 2017, Powertrain Chair 2016, Powertrain Co-Chair 2015), Society of Automotive Engineers (SAE), Institute for Liquid Atomization and Spray Systems (ILASS), Phi Kappa Phi Honor Society, National Society of Professional Engineers, Key Contributor for National Petroleum Council, Portage Athletic Foundation (board member 2016-2017, Vice President 2017-2018), Department of Energy Annual Merit Reviewer 2017-2019, Global Automotive Management Council (GAMC) Board Member (2019-present)

JOURNAL PUBLICATIONS

1. Morris, A. and **McCarthy, J. Jr.,** "The Effect of Heavy-Duty Diesel Cylinder Deactivation on Exhaust Temperature, Fuel Consumption, and Turbocharger Performance up to 3 bar BMEP," SAE 2020-01-1407, 4/14/2020, https://doi.org/10.4271/2020-01-1407.
2. Neely, G., Sharp, C., Pieczko, M., and **McCarthy, J. Jr.,** "Simultaneous NOx and CO_2 Reduction for Meeting Future CARB Standards Using a Heavy-Duty Diesel CDA-NVH Strategy," SAE Int. J. Engines 13(2):2020, https://www.sae.org/publications/technical-papers/content/03-13-02-0014/, first published online Dec. 10, 2019.

3. Taylor, A. H., Odstrcil, T. E., Ramesh, A. K., Shaver, G. M., Koeberlein, E., Farrell, L. and **McCarthy, J. Jr.,** "Model-Based Compressor Surge Avoidance Algorithm for IC Engines Utilizing Cylinder Deactivation During Motoring Conditions," International Journal of Engine Research, October 29, 2019, https://doi.org/10.1177/1468087419883477.
4. Vos, K. R., Shaver, G. M., Joshi, M. and **McCarthy, J. Jr.,** "Implementing Variable Valve Actuation on a Diesel Engine at High-Speed Idle Operation for Improved Aftertreatment Warm-Up," International Journal of Engine Research, September 10, 2019, https://doi.org/10.1177/1468087419880639.
5. Vos, K. R., Shaver, G. M., Ramesh, A. K. and **McCarthy, J. Jr.,** "Strategies for using Valvetrain Flexibility instead of Exhaust Manifold Pressure Modulation for Diesel Engine Gas Exchange and Thermal Management Control," International Journal of Engine Research, September 6, 2019, https://doi.org/10.1177/1468087419880634.
6. Vos, K. R., Shaver, G. M., Ramesh, A. K., **McCarthy, J. Jr.,** and Farrell, L., "Impact of Cylinder Deactivation and Cylinder Cutout via Flexible Valve Actuation on Fuel Efficient Aftertreatment Thermal Management at Curb Idle," Frontiers in Mechanical Engineering, August 21, 2019, https://doi.org/10.3389/fmech.2019.00052.
7. Gosala, D. B., Shaver, G. M., **McCarthy, J. E., Jr.,** and Lutz, T. P., "Fuel-Efficient Thermal Management in Diesel Engines via Valvetrain-enabled Cylinder Ventilation Strategies," International Journal of Engine Research, August 2, 2019. https://doi.org/10.1177/1468087419867247.
8. Allen, C. M., Gosala, D. B., Joshi, M. C., Shaver, G. M., Farrell, L. and **McCarthy, J. Jr.,** "Experimental Assessment of Diesel Engine Cylinder Deactivation Performance during Low Load Transient Operations," International Journal of Engine Research, June 24, 2019, https://doi.org/10.1177/1468087419857597.
9. Roberts, L. and **McCarthy, J. Jr.**, "Design and Development of a Roller Follower Hydraulic Lash Adjustor to Eliminate Lash Adjustment and Reduce Noise in a Serial Production Diesel Engine," SAE 2018-01-1766, 9/10/18, https://doi.org/10.4271/2018-01-1766.
10. Ramesh, A. K., Odstrcil, T. E., Gosala, D. B., Shaver, G. M., Nayyar, S., Koeberlein, E. and **McCarthy, J. Jr.,** "Reverse Breathing in Diesel Engines for Aftertreatment Thermal Management," International Journal of Engine Research, July 13, 2018, https://doi.org/10.1177/1468087418783118.
11. Gosala, D. B., Allen, C. M., Shaver, G. M., Farrell, L., Koeberlein, E., Franke, B., Stretch, D. and **McCarthy, J. Jr.**, "Dynamic Cylinder Activation in Diesel Engines," International Journal of Engine Research, 6/19/18, https://doi.org/10.1177/1468087418779937.
12. Allen, C. M., Gosala, D. B., Shaver, G. M. and **McCarthy, J. Jr**., "Comparative Study of Cylinder Deactivation Transition Strategies on a Diesel Engine," International Journal of Engine Research, 4/13/2018, doi.org/10.1177/1468087418768117.
13. Joshi, M., Gosala, D., Allen, C., Srinivasan, S., Ramesh, A., VanVoorhis, M., Taylor, A., Vos, K., Shaver, G., **McCarthy, J. Jr.,** Farrell, L. and Koeberlein, E., "Diesel Engine Cylinder Deactivation for Improved System Performance over Transient Real-World Drive Cycles," SAE 2018-01-0880, 4/3/2018, https://doi.org/10.4271/2018-01-0880.
14. Archer, A. and **McCarthy, J. Jr.,** "Quantification of Diesel Engine Vibration Using Cylinder Deactivation for Exhaust Temperature Management and Recipe for Implementation in Commercial Vehicles," SAE 2018-01-1284, 4/3/2018, https://doi.org/10.4271/2018-01-1284.
15. Ramesh, A. K., Gosala, D. B., Allen, C., Joshi, M., **McCarthy, J. Jr.,** Farrell, L., Koeberlein E. and Shaver, G., "Cylinder Deactivation for Increased Engine Efficiency and Aftertreatment Thermal Management in Diesel Engines," SAE 2018-01-0384, 4/3/2018, https://doi.org/10.4271/2018-01-0384.

16. Chandras, P., **McCarthy, J. Jr.** and Stretch, D., "Effect of Intake Valve Profile Modulation on Passenger Car Fuel Consumption," SAE 2018-01-0379, 4/3/2018, https://doi.org/10.4271/2018-01-0379.
17. Brown, J., **McCarthy, J. Jr.** and Brownell, S., "Frictional Differences Between Rolling and Sliding Interfaces for Passenger Car Switching Roller Finger Followers," SAE 2018-01-0382, 4/3/2018, https://doi.org/10.4271/2018-01-0382.
18. Vos, K., Shaver, G. M., **McCarthy, J. Jr.** and Farrell, L., "Utilizing Production Viable Valve Strategies at Elevated Speeds and Loads to Improve Volumetric Efficiency via Intake Valve Modulation," Frontiers in Mechanical Engineering, 2/26/2018, 10.3389/fmech.2018.00002.
19. Vos, K., Shaver, G. M., Lu, X., Allen, C. M., **McCarthy, J. Jr.**, Farrell, L., "Improving Diesel Engine Efficiency at High Speeds and Loads Through Improved Breathing Via Delayed Intake Valve Closure Timing, International Journal of Engine Research, 12/8/2017, https://doi.org/10.1177/1468087417743157.
20. Gosala, D. B., Ramesh, A. K., Allen, C. M., Joshi, M. C., Taylor, A. H., Van Voorhis, M., Shaver, G. M., Farrell, L., Koeberlein, E., **McCarthy, J. Jr.** and Stretch, D., "Diesel Engine Aftertreatment Warm-Up Through Early Exhaust Valve Opening and Internal Exhaust Gas Recirculation During Idle Operation," International Journal of Engine Research, 9/20/2017, 10.1177/1468087417730240.
21. Joshi, M. C., Gosala, D. B., Allen, C. M., Vos, K., Van Voorhis, M., Taylor, A., Shaver, G. M., **McCarthy, J. Jr.,** Stretch, D., Koeberlein, E. and Farrell, L., "Reducing Diesel Engine Drive Cycle Fuel Consumption through Use of Cylinder Deactivation to Maintain Aftertreatment Component Temperature during Idle and Low Load Operating Conditions," Frontiers in Mechanical Engineering, 8/8/2017, https://doi.org/10.3389/fmech.2017.00008.
22. Ramesh, A. K., Shaver, G. M., Allen, C. M., Gosala, D. B., Nayyar, S., Parra, C., D. M., Koeberlein, E. and **McCarthy, J., Jr.,** "Utilizing Low Airflow Strategies, Including Cylinder Deactivation, to Improve Fuel Efficiency and Aftertreatment Thermal Management," International Journal of Engine Research, 3/14/2017, https://doi.org/10.1177/1468087417695897.
23. Gosala, D. B., Allen, C. M., Ramesh, A., K., Shaver, G. M., **McCarthy, J. Jr.,** Stretch, D., Koeberlein, E. and Farrell, L., "Cylinder Deactivation During Dynamic Diesel Engine Operating Conditions," International Journal of Engine Research, 2/1/2017, https://doi.org/10.1177/1468087417694000.
24. Halbe, M., Pietrzak, B., Fain, D., Shaver, G., **McCarthy, J. Jr.,** Ruth, M. and Koeberlen E., "Oil Accumulation and First Fire Readiness Analysis of Cylinder Deactivation in Diesel Engines,", Frontiers in Mechanical Engineering, 3/6/2017, https://doi.org/10.3389/fmech.2017.00001.
25. Lu, X, Ding, C., Ramesh, A. K., Shaver, G. M., Holloway, E., **McCarthy, J., Jr.**, Ruth, M., Koeberlein, E. and Nielsen, D., "Impact of Cylinder Deactivation on Diesel Engine Aftertreatment Thermal Management and Efficiency at Highway Cruise Conditions, Frontiers in Mechanical Engineering: Engine and Automotive Engineering, 8/24/15, https://doi.org/10.3389/fmech.2015.00009.
26. Ding, C., Roberts, L., Fain, D., Ramesh A. K., Shaver, G., **McCarthy, J., Jr.**, Ruth, M., Koeberlein, E., and Nielsen, D., "Fuel Efficient Exhaust Thermal Management for Compression Ignition Engines During Idle via Cylinder Deactivation and Flexible Valve Actuation," International Journal of Engine Research, 8/12/15, https://doi.org/10.1177/1468087415597413.
27. Garg, A., Magee, M., Ding, C., Roberts, L., Shaver, G., Koeberlein, E., Holloway, E, Shute, R., Koeberlein, D. **McCarthy, J., Jr.**, and Nielsen, D., "Fuel Efficient Exhaust Thermal Management using Cylinder Throttling via Intake Valve Closing Timing Modulation," Journal of Automotive Engineering, 6/15/15, https://doi.org/10.1177/0954407015586896.

28. Roberts, L., Magee, M., Shaver, G., Garg, A., **McCarthy, J., Jr.**, Koeberlein, E., Holloway, E, Shute, R., Koeberlein, D. and Nielsen, D., “Modeling the Impact of Early Exhaust Valve Opening on Exhaust Aftertreatment Thermal Management and Efficiency for Compression Ignition Engines,” International Journal of Engine Research, 10.1177/1468087414551616, 10/6/2014.
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2. Gosala, D. B., Raghukumar, H., Allen, C. M., Shaver, G. M., **McCarthy, J. Jr.,** and Lutz, L., Firing Pattern Design for Diesel Engine Dynamic Cylinder Activation, under peer review
3. Joshi, M. C., Gosala, D. B., Shaver, G. M., **McCarthy, J. Jr.,** and Farrell, L.,, Exhaust valve profile modulation for improved diesel engine curb idle aftertreatment thermal management, under peer review

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2. Liskar, P, Stretch D. A., **McCarthy, J. E., Jr.**, Gillette, N. P., and Radulescu, A. D., “Valvetrain with Rocker Arm Housing Magnetic Latch,” Patent # 10,731,517, Aug. 4, 2020.
3. VanWingerden, M., Nielsen, D. J. and **McCarthy, J. E., Jr.**, “Rocker Arm Assembly For Engine Braking,” Patent #10,690,024, June 23, 2020.
4. Brown, L. and **McCarthy, J. E., Jr.**, “Hydraulic Lash Adjuster Assembly Sleeves,” Patent #10,690,017, June 23, 2020.
5. Roberts, L., Matson, K., Wright, D., **McCarthy, J. E., Jr.**, Vance, M. and Schultheis, O., “Engine Valve Lifter Having Anti-Rotation Plug,” Patent #10,690,016, June 23, 2020.
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7. **McCarthy, J. E., Jr.**, Nielsen, D. J. and Bishnoi, K., “Rocker Arm Assembly,” Patent #10,626,758, Apr. 21, 2020.
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9. **McCarthy, J. E., Jr.** and Vance, M., “Switching Rocker Arm,” Patent #10,605,125, Mar. 31, 2020.
10. Zurface, A. and **McCarthy, J. E., Jr.**, “Cylinder deactivation deactivating roller finger follower having improved packaging,” Patent # 10,590,814, Mar. 17, 2020.
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12. **McCarthy, J. E., Jr.**, Nielsen, D. J. and Cousin, C., “Cylinder Deactivation Control and Methods,” Patent #10,563,549, Feb. 18, 2020.

13. **McCarthy, J. E., Jr.** and Wetzel, P. W., "Split Axial Cam Shifting System Variable Valve Actuation Functions," Patent #10,544,708, Jan. 28, 2020.
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15. Wetzel, P. W., Nielsen, D. J. and **McCarthy, J. E., Jr.**, "Axial Cam Shifting Valve Assembly with Additional Discrete Valve Event," Patent #10,526,928, Jan. 7, 2020.
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2. **McCarthy, J., Jr**., Theissl, H., Walter, L., "Improving Commercial Vehicle Emissions and Fuel Economy with Engine Thermal Management Using Variable Valve Actuation," ATZ Live International Engine Congress 2017, Baden-Baden, Internationaler Motorenkongress 2017, pp 591-618, Feb. 21-22, 2017 (on line version https://rd.springer.com/chapter/10.1007/978-3-658-17109-4_39).
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6. **McCarthy, J. E., Jr.,** Bamber, D. and Ambrose, S., "Exhaust Tailpipe Fuel Spray Optimization and Fuel Usage Rates for Operating an Exhaust Aftertreatment System on a Heavy-Duty Diesel Engine Powered Vehicle," ILASS2010-177, 22th Annual ILASS-Americas Conference, May 16-19, 2010, Cincinnati, OH.
7. **McCarthy, J. E., Jr.,** "Methodology for Using Fuel Spray Measurements in a Diesel Engine Aftertreatment Exhaust Simulation," 20th Annual ILASS-Americas Conference, May 15-18, 2007, Chicago, IL.
8. **McCarthy, J. E., Jr.** and Senser, D. W., "The Influence Of Air Supply Pressure On Paint Transfer," Extended Abstracts, ILASS-Americas 94, 7th Annual Conference on Liquid Atomization and Spray Systems, Bellevue, Washington, May 31-June 3, 1994, Pages 30-34.
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2. Poojary, D., Nicole, J., **McCarthy, J., Jr.,** Yang, H., "Improved System Performance and Reduced Cost of a Fuel Reformer, LNT, and SCR Aftertreatment System Meeting Emissions Useful Life Requirements," Invited Talk for the Cross-Cut Lean Exhaust Emissions Reduction Simulations (CLEERS) Technical Focus Group, Dec. 9th, 2010.
3. Poojary, D., Nicole, J., **McCarthy, J., Jr.,** Yang, H., "Improved System Performance and Reduced Cost of a Fuel Reformer, LNT, and SCR Aftertreatment System Meeting Emissions Useful Life Requirements," 2010 Directions in Energy-Efficiency and Emissions Research (DEER) Conference, Sept. 30th, 2010.
4. Strots, V., Griffin, G., Dykes, E., and **McCarthy, J.,** "LNT-SCR System for Heavy-Duty On-Highway Vehicles," 2010 MinNOx Conference June 2010
5. **McCarthy, J., Jr.,** "Meeting Worldwide Emission Standards with Eaton's Urea-Free, Durability-Proven, Fuel-Efficient and Compact Aftertreatment System," Invited Talk at the VDV-Akademie-Seminar, Cologne, Germany, June 16-17, 2010
6. **McCarthy, J., Jr.**, "Fuel Reformer, LNT and SCR Aftertreatment System Meeting Emissions Useful Life Requirements," 2009 Directions in Energy-Efficiency and Emissions Research (DEER) Conference, August 3-6, 2009, Dearborn, MI.
7. **McCarthy, J., Jr.** and W. Taylor, III, "LNT+SCR Systems for Medium-Heavy Duty Application: A Systems Approach," 13th Diesel Engine-Efficiency and Emission Research (DEER) Conference, August 13-16, 2007, Detroit, MI.
8. **McCarthy, J. E., Jr.** and Senser, D. W., "Paint Transfer Simulation of Electrostatic Air Paint Sprays," AIChE 8th International Coating Process Science and Technology Symposium, New Orleans, LA, February 25-29, 1996.
9. **McCarthy, J. E., Jr.,** Senser, D. W. and Braslaw, J., "Effect of Operating Variables on Transfer Efficiency and Charge to Mass Ratio in Electrostatic Air Sprays," Advanced Coatings Technology Conference, Dearborn, MI, November 7-9, 1995.
10. **McCarthy, J. E., Jr.** and Senser, D. W., "Modeling Electrostatic Air Paint Sprays," Advanced Coatings Technology Conference, Dearborn, MI, November 7-9, 1995.
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1. **McCarthy, J. E., Jr.,** Lefebvre, A. H. and Senser, D. W., "Drop Rebound From A Small Workpiece With An Air Applicator," CIDMAC Annual Report Fiscal Year 1991-92, Purdue University, The Industrial Partner of the Engineering Research Center for Intelligent Manufacturing Systems by the National Science Foundation, Pages 170-175.
2. **McCarthy, J. E., Jr.,** Lefebvre, A. H. and Senser, D. W., "Basic Studies on Spray Coating: Particle Rebound from a Flat Plate Using a Conventional Air Applicator," CIDMAC Annual Report Fiscal Year 1990-91, Purdue University, The Industrial Partner of the Engineering Research Center for Intelligent Manufacturing Systems by the National Science Foundation, Pages 170-173.

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Summary, Impact & Vision.

Greg Shaver is a Full Professor, University Faculty Scholar, and College of Engineering Early Career Research Award recipient. He joined the Purdue Faculty in 2006. He is focused on creating challenging, interesting, relevant, career-launching research and learning opportunities for Purdue students. His research program is dedicated to clean, safe, and efficient commercial vehicles – via advanced diesel & natural gas engine systems/controls, powertrain electrification, and vehicle automation/connectivity. His efforts are well known in the industry and regulatory agencies, including the U.S. EPA and California Air Resources Board. For example, in Jan. 2020 the EPA described in some detail some of the key findings of Dr. Shaver's research efforts in an "Advance Notice of Proposed Rulemaking" for heavy-duty, on-road engines. This is a result of Greg's students and industry collaborators demonstrating that future diesel engines can simultaneously reduce emissions (NOx and soot), fuel consumption, and CO_2 emissions through the use of variable valve actuation (VVA) and cylinder deactivation. Greg's students have published more than 120 peer-reviewed journal and conference papers. Greg has directed the research efforts of more than 130 current/former Purdue students (58 graduate, 75 undergraduate). Of his 45 former graduate students (17 PhD, 28 MSME) one-third are women, two-thirds are now working at industry partner companies, and two are tenure-track faculty (1 assistant, 1 associate). Greg is, or has been, the PI for ~$19,000,000 in funded research (~50/50 split between industry & government funding), of which ~$14,300,000 is for research on the Purdue campus ($12,000,000 for research directly within his research team). Funding sources include ARPA-E, DOE, Cummins, Deere, Eaton, NSF, EPA, Caterpillar, and GM. Greg earned graduate (PhD 2005, MSME 2004) and undergraduate (BSME 2000 w/ highest distinction) degrees from Stanford and Purdue, respectively.

Research and Professional Experience.

- Purdue University School Mechanical Engineering Full Professor (July 1, 2016 – present), Associate Professor (July, 1, 2011 – June 30, 2016), and Assistant Professor (August 2006-June 2011)
- Stanford University Graduate Research Assistant, 2000-05
- Purdue University Co-Op Student for AlliedSignal Inc. (now Honeywell) Aerospace 1996-1999

Honors and awards.

- 2019 SAE John Johnson Best Paper Award for Outstanding Research in Diesel Engines
- 2014 Early Career Excellence in Research Award, Purdue University College of Engineering
- 2014 Purdue University Faculty Scholar
- 2013 Ralph Teetor Educational Award
- Best paper in Journal of Automobile Engineering for year 2012
- 2011 SAE Max Bentele Award for Engine Technology Innovation
- 2003, 2004, & 2005 American Control Conference - best presentation in session award
- 2005 Best paper in the ASME Journal of Dynamic Systems Measurement and Control

University service highlights.

- Search Committees for Purdue's current Engineering Dean & Mechanical Engineering Head
- Engineering Faculty Affairs Committee
- Mechanical Engineering Leadership Team
- Purdue's Inaugural Coaching and Resource Network
- Search Committee Chair, Autonomous and Connected Systems, Mechanical Engineering

Education and Training

- Ph.D./Masters Mechanical Engineering, Stanford University, June 2005
- B.S.M.E. Mechanical Engineering, Purdue University, 2000, with highest distinction

Publications and Presentations

Refereed journal papers: 75 (70 published/accepted, 3 in journal review, 2 in preparation)

1. Gregory M. Shaver*, Matthew J. Roelle, J. Christian Gerdes, Patrick A. Caton and Christopher F. Edwards, Dynamic Modeling of HCCI Engines Utilizing Variable Valve Actuation, *ASME Journal of Dynamic Systems, Measurement and Control*, vol. 127, no. 3, pp. 374-381, September 2005 (Selected as the best paper published in the Journal of Dynamic Systems, Measurement and Control, 2005)
2. Gregory M. Shaver*, Matthew J. Roelle, J. Christian Gerdes, Jean-Pierre Hathout, Jasim Ahmed, Aleksandar Kojic, Patrick A. Caton and Christopher F. Edwards, A Physics-Based Approach to Control of HCCI Engines with Variable Valve Actuation, *International Journal of Engine Research*, vol. 6, no. 4, pp. 361-375(15), July 2005
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37. Karla Stricker*, Lyle Kocher, Dan Van Alstine, and Gregory M. Shaver, Guaranteed Convergence of a High-Gain Input Observer Robust to Measurement Uncertainty: Application to Effective Compression Ratio Estimation, *2012 IFAC Workshop*
38. Carrie M. Hall, Dan Van Alstine, Lyle Kocher, and Greg Shaver, Combustion Timing Modeling & Control Framework for Biodiesel/Diesel Blends During Pre-mixed Combustion, *2012 Dynamic Systems and Control Conference*.
39. Dat Le*, Jin Shen*, Neha S. Ruikar, and Gregory M. Shaver, Dynamic Modeling of Piezo-Electric Injector-Enabled Rate Shaping, *American Control Conference*, 2013.
40. Jin Shen*, Neha Ruikar*, Dat Le and Gregory M. Shaver, Model-based Within-a-Cycle Estimation of Rate Shaping for a Piezoelectric Fuel Injector*, American Control Conference*, 2013.
41. Lyle Kocher*, Mark Magee, Dan Van Alstine, Gregory M. Shaver , A Nonlinear Model-Based Controller for Premixed Charge Compression Ignition Combustion Timing in Diesel Engines, *American Control Conference*, 2013.
42. Dat Le*, Bradley W. Pietrzak, and Gregory M. Shaver, Rate Shaping Estimation and Control of a Piezoelectric Fuel Injector, *2013 Dynamics Systems and Control Conference*, 2-2013
43. Carrie M. Hall*, Dan Van Alstine, and Gregory M. Shaver, Flatness-Based Control of Mode Transitions between Conventional and Premixed Charge Compression Ignition on a Modern Diesel Engine with Variable Valve Actuation, *2013 Dynamics Systems and Control Conference*, 2-2013
44. Bradley Pietrzak*, Dat Le, and Gregory M. Shaver, Model-Based Estimation of Piezoelectric Fuel Injector Parameters, 2014 American Control Conference
45. Adam Fogarty, Kevin Oswald, Gregory M. Shaver, Peter Meckl, and Vahid Motevallii, Design of a Rear Suspension Cradle for usage in a Parallel-Through-the-Road PHEV, 2014-01-1928

46. Ashish Vora, Haotian Wu, Chuang Wang, Yili Qian, Gregory M. Shaver, Peter Meckl, Haiyan Zhang, Development of a SIL, HIL and Vehicle Test-Bench for Model-Based Design and Validation of Hybrid Powertrain Control Strategies, 2014-01-1906, in review
47. Leighton Roberts, Mark Magee, David Fain, Greg Shaver, Eric Holloway, Raymond Shute, James McCarthy, Douglas Nielsen, Edward Koeberlein, Raymond Shute, and David Koeberlein, Impact of Cylinder Deactivation at Idle on Thermal Management and Efficiency, 2014 SAE COMVEC
48. Leighton Roberts, Mark Magee, David Fain, Greg Shaver, Eric Holloway, Raymond Shute, James McCarthy, Douglas Nielsen, Edward Koeberlein, Raymond Shute, and David Koeberlein, Impact of Early Exhaust Valve Opening on Exhaust Thermal Management and Efficiency for Compression Ignition Engines, 2014 SAE COMVEC
49. Dat Le*, Bradley Pietrzak, and Gregory M. Shaver, Stability Analysis of Dynamic Surface Control for Piezoelectric Fuel Injection During Rate Shaping, 2014 Dynamic Systems and Control Conference
50. Ashish P. Vora, Xing Jin, Vaidehi Hoshing, Xiaofan Guo, Gregory M. Shaver, Wallace Tyner, Eric Holloway, Subbarao Varigonda, and Joachim Kupe, Simlation Framework for the Optimization of HEV Design and Control Parameters: Incorporating Battery Degradation in a Lifecycle Economic Analysis, to appear in the 2015 IFAC Workshop on Engine and Powertrain Control, Simulation and Modeling, August, 2015
51. Shubham Agrawal, Xiaohui Liu, Xing Jin, Ashish Vora, Gregory Shaver, Srinivas Peeta, J. Eric Dietz, and Joseph Pekny, Quantifying the Impacts of Electric Vehicle Travel Patterns on Battery Life Span, 96^{th} Annual Meeting of the Transportation Research Board, January 8^{th} – 12^{th}, 2017, Washington D.C.
52. Xing Jin, Ashish P. Vora, Vaidehi Hoshing, Tridib Saha, Gregory M. Shaver, Oleg Wasynczuk, and Subbarao Varigonda, Applicability of Available Li-Ion Battery Degradation Models for System and Control Algorithm Design, 2017 ACC,
53. Xing Jin, Ashish P. Vora, Vaidehi Hoshing, Tridib Saha, Gregory M. Shaver, R. Edwin Garcia, Oleg Wasynczuk, and Subbarao Varigonda, Physically-based Reduced-Order Capacity Loss Model for Graphite Anodes in Li-Ion Battery Cells, 2017 ACC,
54. Ana Guerrero de la Pena, Navin Davendralingam, Ali K. Raz, Vivek Sujan, Daniel DeLaurentis, Gregory M. Shaver, and Neera Jain, Modeling Freight Transportation as a System-of-Systems to Determine Adoption of Emerging Vehicle Technologies, Proceedings of the 2018 International Conference on Transportation and Development, Pittsburgh, PA, July 15-18 2018
55. Joshi, M., Gosala, D., Allen, C., Srinivasan, S., Ramesh, A., VanVoorhis, M., Taylor, A., Vos, K., Shaver, G., McCarthy, J. Jr., Farrell, L. and Koeberlein, E., "Diesel Engine Cylinder Deactivation for Improved System Performance over Transient Real-World Drive Cycles," SAE 2018-01-0880, 4/3/2018.
56. Ramesh, A. K., Gosala, D. B., Allen, C., Joshi, M., McCarthy, J. Jr., Farrell, L., Koeberlein E. and Shaver, G., "Cylinder Deactivation for Increased Engine Efficiency and Aftertreatment Thermal Management in Diesel Engines," SAE 2018-01-0384, 4/3/2018,
57. A. Guerrero de la Peña, N. Davendralingam, A. Raz, G. Shaver, D. DeLaurentis, Vivek A. Sujan, and N. Jain "Modeling the Combined Effect of Powertrain Options and Autonomous Technology on Vehicle Adoption and Utilization by Line-haul Fleets." *Proceedings of the 2019 IEEE Intelligent Transportation Systems Conference*, Auckland, New Zealand, October 27-30, 2019

Books and chapters in books.

1. Gregory M. Shaver, *Enabling Simultaneous Reductions in Fuel Consumption, NO_x, and CO_2 via Modeling and Control of Residual-Affected Low Temperature Combustion*, Chapter in: Emerging Environmental Technologies, Springer 2008 (peer-reviewed)

Other publications.

1. Gavin Maxwell*, Cameron Mackay, Ian Jowsey, Seema Bajaria, Katherine Kudrycki, Saroja Ramanujan, Gregory M. Shaver, Christina Friedrich, David Lockley, F. Reynolds, and J. Fentem, In-silico Modelling of Skin Sensitization, 20th Meeting of the European Research Group on Experimental Contact Dermatitis, Lyon, October 20-22, 2006
2. Cameron Mackay*, Seema Bajaria*, Gregory M. Shaver, Katherine Kudrycki, Saroja Ramanujan, Thomas Paterson, Christina Friedrich, G. Maxwell, I. Jowsey, D. Lockley, F. Reynolds, and J. Fentem, In silico modeling of skin sensitization, Proceedings of the Joint Meeting of The British Toxicology Society & The In Vitro Toxicology Society, University of York, York, UK, Toxicology 231 (2007) 100-103
3. David B. Snyder and Gregory M. Shaver, Biodiesel Sensing Technology Development for Fuel Flexible Diesel Engine, Transportation Research Board 87th Annual Meeting, 1/13/2008
4. Gregory M. Shaver, *Enabling Simultaneous Reductions in Fuel Consumption, NO_x, and CO_2 via Modeling and Control of Residual-Affected Low Temperature Combustion*, Invited talk, 236th American Chemical Society National Meeting, Philadelphia, PA, August 17-21, 2008

Contributed conference/symposium presentations.

1. Gavin Maxwell*, C. Mackay, S. Bajaria, K. Kudrycki, G. Shaver, S. Ramanujan, I. Jowsey, D. Lockley, C. Friedrich, *Poster* - An in silico approach to aid is assessing the risk of chemical-induced skin sensitization, Poster, 6th World Congress on Alternatives & Animal Use in the Life Sciences, August 21st-25th, 2007 Tokyo, Japan.
2. Cameron Mackay*, Seema Bajaria, G. Maxwell, K. Kudrycki, G. Shaver, S. Ramanujan, I. Jowsey, D. Lockley, C. Friedrich, *Poster* - An in silico approach to aid is assessing the risk of chemical-induced skin sensitization, Poster, 8th International Conf. on Systems Biology, October 1-6, 2007, Long Beach, CA
3. Gavin Maxwell*, Cameron MacKay, Seema Bajaria, Katherine Kudrycki, Gregory M. Shaver, Saroja Ramanujan, Ian Jowsey, Dave Lockley, and Christina Friedrich, *Poster* - Assuring safety without animal testing: Skin allergy case study – Application of an in silico modeling approach, Poster, EPAA 2007 Annual Conference, November 5, 2007, Brussels
4. Karla Stricker*, Dan Van Alstine, Lyle Kocher, Rajani Modiyani, Ed Koeberlein, and Paul Meckl, Gregory Shaver*, Poster - Reducing Emissions and Fuel Consumption via Advanced Mode Combustion Control in Engines with Flexible Valve Actuation*, Symposium on Control and Modeling of Alternative Energy Systems, Univ. of Illinois at Urbana-Champaign, 4/2/2009
5. David Snyder*, Michael Bunce, Carrie Hall, Gayatri Adi, Jeremy Koehler, Bernie Davila, Gregory Shaver*, Poster - Clean and Efficient Fuel-Flexible Combustion of Alternative Diesel Fuels Via Closed-Loop Control*, Symposium on Control and Modeling of Alternative Energy Systems, Univ. of Illinois at Urbana-Champaign, 4/2/2009

Invited colloquium, seminar series, and conf. presentations. (40, including: 6 international)

1. "Modeling for Control of HCCI Engines" –Robert Bosch Corporation Research and Technology Center, Palo Alto, CA August 15th 2003
2. *Contraction and Sum of Squares Analysis of HCCI Engines*, Robert Bosch Corporation, Stuttgart, Germany, 9/2004
3. "Physics-based Modeling and Control of HCCI Engines" – Mechanical Engineering Department, California Polytechnic State University, June 2005
4. "Physics-based Modeling and Control of HCCI Engines" – Entelos, Foster City, CA 6/2005
5. *Physics-based Modeling and Control of HCCI Engines*, Center for Automotive Research, The Ohio State Univ., 8/2005
6. "From Physics-based Modeling & Control of HCCI to Physiology-based Modeling & Control of Human Disease" Stanford University, October 14th, 2005 ME201 Seminar: Introduction to research in mechanical engineering & strategies for getting involved. Audience M.S. students and undergraduates
7. *Modeling, Design, Utilization & Control of Novel Combustion Systems*, Oak Ridge Nat. Lab, 11/29/2006
8. *Modeling, Design, & Control of Novel Combustion Systems*, Purdue ASME Luncheon, 1/10/2008
9. Clean and Efficient Fuel-Flexible Combustion of Alternative Diesel Fuels via Closed-loop Control, IUPUI, 4/22/2008
10. Gregory M. Shaver, *Enabling Simultaneous Reductions in Fuel Consumption, NO_x, and CO_2 via Modeling and Control of Residual-Affected Low Temperature Combustion*, Invited talk, 236th American Chemical Society National Meeting, Philadelphia, PA, August 17-21, 2008
11. *Purdue IndyGo Biodiesel Study*, Indiana MPO Annual Statewide Conference on Freight, Fiber, and Fuel – Planning for Transportation, Mobility and Resources in a Global Economy, Century Center, South Bend, IN 10/9/2008
12. Demo to middle school students for MINDS (Mastering Ideas Necessary for Developing Students) Program "*Next Generation Engine Modeling and Control Research at Purdue University*", October 18th, 2008, event held at Purdue for middle school students to give them a better understanding of engineering.
13. *Advances in Clean and Efficient Engine Technology*, Purdue ME290 Seminar, 2-12-2009
14. Presentation and lab tour at Herrick Labs, *Fuel Flexible Combustion for the Clean & Efficient Use of Biodiesel*, for Purdue University Women in Engr. Program - Innovation to Reality Program, 2-19-2009
15. *Plenary Presentation – Modeling and Control of Next Generation IC Engines*, 2nd Intl. Conf. and Exhibition on Advances in Energy Research, December 2009, IIT Bombay
16. Advanced Mode & Fuel-Flexible Combustion Control Activities at Purdue University, March 9th, 2010, IFP, Paris, France
17. Model-Based Closed-Loop Control of IC Engine Fuel Injection, Gas Exchange, and Combustion Processes, Lindbergh Lecture, University of Wisconsin – Madison, March 10, 2011
18. Model-Based Closed-Loop Control of IC Engine Fuel Injection, Gas Exchange and Combustion Processes; Flow, Heat Transfer and Combustion Workshop, Shanghai Jiao Tong Univ., June 2-3, 2011
19. Fuel Adaptive Diesel Engine Control, 2011 Adv. Engine Control Symposium, Tianjin University, November 16th, 2011

20. *Plenary Pres.* - Model-Based Closed-Loop Control of IC Engine Fuel Injection, Gas Exchange, and Combustion Processes, 3rd Intl. Conf. and Exhibition on Adv. in Energy Res., Dec. 2011, IIT Bombay
21. Model-Based Closed-Loop Control of Advanced Engine Systems and Combustion Strategies, Ford Research and Innovation Center, Dearborn, MI, January 23, 2012
22. Model-Based Closed-Loop Control of Advanced Engine Systems and Combustion Strategies, The Ohio State University, February 9th, 2012
23. Fuel Adaptive Diesel Engine Control, John Zink Company, February 20th, 2012
24. Model-Based Closed-Loop Control of Advanced Engine Systems and Combustion Strategies, University of Houston, March 29th, 2012
25. Engine Model and Control Research at Purdue, Advanced Engine Control Symposium, University of Michigan, April 23rd, 2012
26. Development of High Efficiency, Environmentally Friendly Vehicles, Science on Tap, August 23rd, 2012
27. Automotive Research at Purdue, VIT (Vellore India), January 20th, 2013
28. Model-Based Engine Algorithm Dev. for Control and Virtual Sensing, Mich. Tech Univ. April 4th, 2013
29. Model-Based Engine Algorithm Development for Control and Virtual Sensing, 2013 University of Wisconsin Engine Research Center Symposium, June 5th, 2013
30. Engine Systems Integration and Control Research at Purdue (Invited Talk), Ford, August 2014
31. Using Cylinder Deactivation to Improve Diesel Engine Fuel Efficiency via Improved Aftertreatment Thermal Management, Chicago, September 2017
32. Improving Heavy-Duty Diesel Engine System Fuel Economy via Cylinder Deactivation for Fuel-Efficient Aftertreatment System Temperature Maintenance, DOE Crosscut Meeting, Detroit, July 2017
33. Opportunities and Benefits of Commercial Truck Platooning, Indiana Department of Transportation Connected and Autonomous Vehicle Summit, Indianapolis, June 2017
34. (Invited Talk & Panelist), Work Truck Show, Indianapolis, March 2018
35. Control Challenges for CI Engines Incorporating Valvetrain Flexibility for Efficiency and Aftertreatment Thermal Management (Keynote), Symposium for Combustion Control, Aachen Germany, May 2018
36. Standards Role in Managing Technology Disruptions (Invited Talk & Panelist), 2018 SAE COMVEC
37. High-Efficiency Control Systems Development for Connected and Automated Class 8 Trucks (Invited Talk), ASME Connected & Automated Vehicle Workshop, Atlanta, September 2018
38. PHEV Viability for MD Trucks & Transit Buses & Expected Engine Operation in Them (Invited Talk & Panelist), ASME Internal Combustion Engine Fall Conference, San Diego, November 2018
39. Fuel-efficient Diesel Engine Thermal Management via Cylinder Deactivation (Invited Talk), Integer Emissions Conference, Indianapolis, December 2018
40. Cummins/Purdue Research Partnership (Invited Talk & Panelist), National Academic of Science and Engineering, Washington D.C., December 2018
41. High-Efficiency Control Systems for Connected Class 8 Trucks, 2019 Work Truck Show, March 6th, 2019
42. Commercial Vehicle Research at Purdue, Alumni Event hosted by GM, Detroit, April 14th, 2019
43. Class 8 Truck Platooning, 2019 MAASTO

44. Class 8 Truck Platooning, 2019 SAE COMVEC, Sept. 10th, 2019

Course Instruction

SEM	COURSE TITLE	COURSE #	# RESPONSES/ # IN COURSE	COURSE EVAL SCORE	PROF EVAL SCORE	DEPT* AVE. PROF. SCORE
F06	Measurement Systems	365	??/??	NA	4.2	3.96
S07	System Modeling and Analysis	375	65/68	4.1	4.3	4.15
F07	System Modeling and Analysis	375	60/72	4.1	4.7	4.15
S08	System Modeling and Analysis	375	51/68	3.9	4.4	4.15
F08	Automatic Control Systems	475	32/35	4.1	4.9	3.95
S09	Automatic Control Systems	475	28/32	4.4	4.6	3.95
F09	Theo. and Des. of Control Sys.	575	27/38	4.2	4.5	4.49
S10	System Modeling and Analysis	375	45/76	3.7	3.4	4.15
F10	Theo. and Des. of Control Sys.	575	25/33	4.6	4.6	
S11	Sys. Modeling and Analysis	375	56/69	3.8	3.9	
F11	Theo. and Des. of Control Sys.	575	28/37	4.3	4.4	
	EcoCAR-Juniors	497	6/8	4.5	4.5	
	EcoCAR-Seniors	497	4/6	3.5	4.5	
S12	Senior Design – EcoCAR	463	4/7	4.3	4.3	
	EcoCAR-Juniors	497	3/4	4.0	4.3	
	EcoCAR-Seniors	497	1/2	5	5	
	Multivariable Control Systems	675	14/20	4.4	4.4	
F12	Theo. and Des. of Control Sys.	575	22/37	4.1	4.3	
	EcoCAR-Juniors	497	2/4	5	4	
S13	Adaptive Control	689	11/25	4.0	3.9	
	Senior Design – EcoCAR	463	3/6	4.8	5.0	
	EcoCAR – Juniors	497	3/3	4.8	4.0	
F13	Theory and Des. of Control Sys.	575	31/39	4.3	4.5	
	EcoCAR – Juniors	497	2/9	5	5	
S14	Multivariable Control Systems	675	9/18	3.8	3.3	
	EcoCAR	497	2/5	4.5	4.5	
F14	Theory and Des. Of Cntl Sys	575	28/34	4.5	4.5	
	Theory and Des. Of Cntl Sys – EPE	575	24/50	4.6	4.7	
S15	Sys. Modeling and Analysis	375	46/96	3.9	4.2	
F15	Measure Control Systems I	365	60/80	3.6	3.4	
S16	Engineering Design	463	15/19	4.6	4.7	
F16	Internal Combustion Engines	540	17/29	4.1	4.3	

SEM	COURSE TITLE	COURSE #	# RESPONSES/ # IN COURSE	COURSE EVAL SCORE	PROF EVAL SCORE	DEPT* AVE. PROF. SCORE
F17	Theory and Design of Control Systems	575	37/58	4.6	4.5	
S18	Multivariable Control Systems	675	17/34	4.1	4.3	
F18	Internal Combustion Engines	540	18/25	3.9	4.2	
F19	Measurement & Control Systems II	375	50/54	4.2	4.3	
S20	Measurement & Control Systems II	375				
F20	Measurement & Control Systems II	375				
Mean				4.3	4.4	
Standard Deviation				0.40	0.42	

Major committee assignments in the Department, School, and/or University.

- Academic Area Chair, Mechanical Engineering Systems, Measurement and Control, Spring 2019 – present
- College of Engineering Faculty Affairs Committee, Fall 2018 – present
- Mechanical Engineering Head Search Committee, Fall 2018 – Spring 2019
- Engineering Dean Search Committee, 2017
- Mechanical Engineering Leadership Team (MELT), Fall 2014 – present
- Mechanical Engineering Graduate Admissions Committee, Fall 2015- present
- Safety Committee (member), Herrick Labs, School of Mechanical Engineering, Spring 2007-present
- Communications Committee (member), School of Mechanical Engineering, Fall 2006-Spring 2008
- Grade Appeals Committee (member), College of Engineering, Spring 2007-Spring 2009
- Graduate Committee (member), School of Mechanical Engineering, Fall 2009-January 2013
- Mechanical Engineering Leadership Team (MELT), Fall 2011-present
- ME Search Committee (member) - November 2012- Spring 2013
- ME Search Committee (member) – October 2014 – April 2015

Administrative duties at Purdue.

- Faculty advisor, Theta Tau Engr. Fraternity (Organizer of the Local and National Rube Goldberg Machine Contest Competitions)
- Faculty advisor, Purdue University EcoCar2 team – designing a plug-in hybrid electric vehicle powertrain for a 2012 Chevy Malibu

Service to government or professional organization.

- Associate Editor, International Federation of Automatic Control (IFAC) Control Engineering Practice Journal, March 2009 – December 2013
- Associate Editor, International Journal of Engine Research, August 2014 – present

- Associate Editor, Frontiers in Engine and Automotive Research, November 2014 - present
- Associate Editor, ASME Journal of Dynamics Systems Measurement and Control, July 2012-2016
- Editorial board, ASME Dynamics Systems and Control Magazine, 1/2012-present
- Session Co-chair and Organizer (Automotive Propulsion Systems) for the 2006 American Control Conference
- Editor, 2007 IFAC Advances in Automotive Control Symposium and Special Journal Issue
- 2008 Purdue Pugwash Undergraduate Research Symposium Poster Judge, 3/20/2008
- Proposal Review Panel Member, NSF Control Systems Program, May 4th-5th, 2008
- ASME Fuels Program Peer Review Panel Member for U.S. Dept. of Energy, National Energy Technology Laboratory, Feb. 2009
- 2009 Sigma Xi Graduate Student Research Awards, Poster Judge, 2/18/2009
- Paper reviewer for: IFAC Control Engineering Practice; Journal of Dynamic Systems, Measurement, and Control; IEEE/ASME Transactions on Mechatronics; IEEE Control Systems Technology; Journal of SAE International; American Control Conference, ASEM International Mechanical Engineering Congress and Exposition; IFAC Symposium on Advances in Automotive Control
- Chairman, Automotive and Transportation Panel, ASME Division of Dynamic Systems and Control, July 2013 – November 2014

Graduate Thesis Committees Chaired (i.e., student for which I am the major professor)

- 14 current, including: 6MSME, 8PhD
- 45 past, including: 28 MSME and 17 PhD

NAME	DEG.	START DATE	GRAD. DATE	CO-CHAIR	TITLE
Anup Kulkarni	MSME		8/2008	----	Investigation of high efficiency, ultra-low emission, advanced model diesel combustion in a validated, flexible and computationally efficient whole engine model
Gayatri Adi	MSME		12/2008	----	An Experimental and Simulation Study of Fuel Consumption and NOx Emission from Bio-fueled Diesel Engines
Michael Bunce	MSME		7/2009	----	Opt. of Soy-Biodiesel Combustion in a Modern Diesel Engine
Rajani Modiyani	MSME		3/2010	----	Effect of Intake Valve Closure Timing on Effective Compression Ration and Gas Exchange Process of a Modern Diesel Engine
David Snyder	DPhD		8/2010	----	Soy-Based Biodiesel Blend Estimation and Accommodation in a Modern Diesel Engine
Chris Satkoski	MSME		12/2010	----	Modeling, Estimation, and Closed Control of Piezo-electric Actuate Fuel Injector
Edward Koeberlein	MSME		12/2011	----	Physics-Based Modeling & Estimation of Exhaust Manifold Filling Dynamics on a Diesel Engine Equipped with Flexible Intake Valve Actuation

NAME	DEG.	START DATE	GRAD. DATE	CO-CHAIR	TITLE
Gayatri Adi	PhD		5/2012	----	Closed-Loop Control for Biodiesel Blends During Mixing Controlled Combustion
Karla Stricker	DPhD		5/2012	----	Turbocharger Map Reduction and Estimation of Effective Compression Ratio in a Modern Diesel Engine Utilizing Flexible Intake Valve Modulation
Bryan Whitney Belt	MSME		12/2012	----	High Voltage Energy Storage System Design for a Parallel-Through-the-Road Plug-In Hybrid Electric Vehicle
Neha Ruikar	MSME		12/2012	----	FPGA/Model – Based Within-a-Cycle Flow Rate Estimation for a Piezo-electric Fuel Injector
Lyle Kocher	DPhD		12/2012	----	Physically-Based Modeling, Estimation, and Control of the Gas Exchange and Combustion Processes for Diesel Engines Utilizing Variable Intake Valve Actuation
Dan Van Alstine	DPhD		5/2013	----	Control-Oriented Modeling and Operating Range Expansion of PCCI Combustion in a Multi-Cylinder Diesel Engine with Flexible Valve Actuation and Variable Fuel Reactivity
Carrie Hall	DPhD		12/2012	----	Fuel-Flexible Combustion Control of Modern Compression-Ignition and Spark-Ignition Engines
Jin Shen	MSME		12/2012	----	Within-a-Cycle Flow Rate Estimation for Piezoelectric Fuel Injection
Dat Le	DPhD		3/2014	----	Model-Based Control of Piezo-Electric Fuel Injection During Rate Shaping Operation
Ashish Vora	DPhD		6/2016	Meckl	Modeling the Impact of Battery Degradation Within Lifecycle Cost Based Design Optimization of Heavy-Duty Hybrid Electric Vehicles
Nishi Railkar	MSME		12/2013	----	Investigation of Operating Range Capability of Gasoline-Fueled Compression Ignition
Chuan Ding	PhD		8/2014	----	Thermal Efficiency and Emission Analysis of Advanced Thermodynamic Strategies in Multi-cylinder Diesel Engines Utilizing Valve Train Flexibility
Mark Magee	MSME		12/2013	----	Exhaust Thermal Management Using Cylinder Deactivation (deposited 1/2014)
Leighton Robert	MSME		7/2014	----	Analysis of the Impact of Early Exhaust Valve Opening and Cylinder Deactivation on Aftertreatment Thermal Management and Efficiency for Compression Ignition Engines
Adam Fogarty	MSME		8/2014	Meckl	High Voltage Rear Electric Drivetrain Design for a Parallel-Through-the-Road PHEV
Bilwa Jadhav	MSME		7/2014	Meckl	Integration and Implementation of High-Voltage Energy Storage Sub-System for a Parallel-Through-The-Road PHEV

NAME	DEG.	START DATE	GRAD. DATE	CO-CHAIR	TITLE
David Fain	MSME		6/2014	----	Operating Range Characterization and Expansion of PCCI in a Multi-Cylinder Diesel Engine w. VVA, Variable Fuel Reactivity and Revised Turbomachinery
Akash Garg	MSME		12/2013	----	Exhaust Thermal Management Using Intake Valve Closing Timing Modulation
Brad Pietrzak	MSME		12/2014	----	Algorithm Development and Analysis for Advanced Engine Technologies Including Piezoelectric Fuel Injection and Variable Valve Actuation
Xing Jin	PhD		12/2017	----	Physics-Based Computationally Efficient Battery Degradation Model and Electric Machine Scaling Strategy for Hybrid Electric Vehicle Design Optimization
Aswin Ramesh	DPhD		8/2018	----	Utilization of Variable Valve Actuation to Improve Fuel Efficiency and Aftertreatment Thermal Management in Diesel Engines
Mayura Halbe	MSME		8/2015	----	Analysis and Algorithm Development for Diesel Engine Systems Utilizing Variable Valve Actuation to Enable Premixed Charge Compression Ignition and Cylinder Deactivation
Lucius Wang	MSME		8/2015	----	Increasing the High Load Limit of Effective Premised Charge Compression Ignition via Intake Valve Closure Modulation and Late Injection
Soumya Nayyar	MSME		5/2016	----	Implementation and Analysis of Reverse Breathing, Rebreathing, and Cylinder Deactivation for Aftertreatment Thermal Management and Overall Efficiency Benefit on Diesel Engines
Sylvia Lu	MSME		8/2016	----	Improving Fuel Economy During High Load Diesel Engine System Operation Through Valve-Train Flexibility
Chaitu Panuganti	MSME	08/2014	8/2016	----	Control-Oriented Modeling, Validation, and Analysis of a Natural Gas Engine Architecture
Dheeraj Gosala	DPhD	08/2014	12/2018	----	Fuel-Efficient Emissions Reduction from Diesel Engines via Advanced Gas Exchange Management
Vaidehi Hoshing	DPhD	08/2014	12/2018	----	Augmented Framework for Economic Viablility-Based Powertrain Design and Emissions Analysis of Medium/Heavy-Duty Plug-In Hybrid Electric Vehicles
Alex Taylor	MSME		8/2016	----	Test Cell Set-Up to Enable Drive-Cycle Testing of a Variable Valve Actuation Enabled Camless Diesel Engine
Troy Odstrcil	MSME		1/2018	----	Variable Valve Actuation Strategies for Improving Aftertreatment System Efficiency in Modern Diesel Engines Over the Heavy-Duty Federal Test Procedure Certification Cycle
Alex Taylor	PhD		12/2018	----	Diesel Engine Air Handling Strategies for Fuel Efficient Aftertreatment Thermal Management & Connected and Automated Class 8 Trucks

NAME	DEG.	START DATE	GRAD. DATE	CO-CHAIR	TITLE
Matthew Van Voorhis	MSME	08/2015	08/2017	----	Implementation of Aftertreatment System to Enable Tailpipe Emissions Measurements of a Variable Valve Actuation Enabled Camless Diesel Engine
Cody Allen	DPhD	08/2014	3/2019	----	Advancing Diesel Engines via Cylinder Deactivation
Kalen Vos	DPhD	08/2015	8/2019	----	Utilizing Valvetrain Flexibility to Influence Gas-Exchange and Reduce Reliance on Exhaust Manifold Pressure Control for Efficient Diesel Engine Operation
Sharon Zhang	DPhD	08/2016	12/2020 (est.)	----	TBD – Natural Gas Engine/Aftertreatment Control for Commercial PHEVs
Sree Harsha Rayasam	MSME	01/2017	12/2018	----	Evaluation of Fuel Savings Due to Powertrain Electrification of Class 8 Trucks
Mrunal Joshi	PhD	08/2015	12/2019	----	Diesel Engine Cylinder Deactivation for Improved System Efficiency while Maintaining Elevated Aftertreatment Temperatures
Brady Black	MSME	08.2018	8/2020 (est.)		TBD – Combining Long-Horizon Predictive Cruise Control and Truck Platooning for Improved Fuel Savings
Ifeoluwa Ibitayo	MSME	08/2017	8/2019	----	Enhanced Class 8 Truck Platooning via Simultaneous Shifting and Model Predictive Control
Shveta Dhamankar	DPhD	08/2018	12/2022 (est.)	----	TBD -
John Foster	MSME	08/2018	7/2020	----	Advanced Control Strategies for Diesel Engine Thermal Management and Class 8 Truck Platooning
Weijin Qiu	DPhD	08/2018	8/2022 (est.)	----	TBD
Ziping Liu	DPhD	08/2017 12/18(GS)	12/2021 (est.)	----	TBD
Chisom Emegoakor	DPhD	08/2018	12/2022 (est.)	----	TBD
Shubham Ashta	DPhD	01/2019	12/2022 (est.)	----	TBD
Sree Harsha Rayasam	PhD	01/2019	8/2021 (est.)	----	TBD
Miles Droege	MSME	08/2019	8/2021 (est.)	----	TBD
Tyler Swedes	MSME	08/2019	8/2021 (est.)	----	TBD
Chufan Jiang	PhD	08/2015 5/19(GS)	12/2021 (est.)	----	TBD

NAME	DEG.	START DATE	GRAD. DATE	CO-CHAIR	TITLE
Shubham Agnihotri	MSME	10/2019	8/2021 (est.)	----	TBD
Vrushali Deshmukh	MSME	08/2019	8/2021 (est.)	----	TBD
Doni Thomas	MSME	8/2020	8/2022 (est.)	----	TBD
Michael Robert Anthony	MSME	8/2020	8/2022 (est.)	----	TBD
Preston Becker	MSME	8/2020	8/2022 (est.)	----	TBD
Devarshi Patel	DPhD	1/2021	8/2025	----	TBD - Starting Jan 2021
Adil Shaikh	DPhD	1/2020	8/2025	----	TBD - Starting Jan. 2021

Undergraduate special projects directed (75).

1. Will Glewen – Spring 2007 (ME497)
2. Justin Ervin – Spring 2007 (ME497)
3. Matthew Carroll – Summer 2007 (ME497), alternative fuels combustion/estimation
4. Elena Washington – Summer 2007 (SURF), alternative fuels combustion/estimation
5. Armando Indrajuana – Summer 2007 (SURF) , alternative fuels combustion/estimation
6. Fang Li – Spring 2008 (ME497)
7. Angeline Blum – Summer 2008 (SURF), VVA/PCCI research project
8. Paul Lang – Fall 2008 (ME497) , VVA/PCCI research project
9. Chris Satkoski – Fall 2008 (ME497), alternative fuels combustion/estimation
10. Jeremy Koehler – Summer 2008, Spring 2009, alternative fuels combustion/estimation
11. Ed Koeberlein – Fall 2008 (ME497), Spring 2009, VVA/PCCI research project
12. Bernie Davila – Fall 2008, Spring 2009 (ME497), , alternative fuels combustion
13. Paul Meckl – Spring 2009, Fall 2009 (ME497), Spring 2011 (ME497), VVA/PCCI research project
14. Wei Yang – Spring 2009
15. Augustine Zhou – Spring 2010 (GEARE), modeling of piezo-electric fuel injection measurements
16. May Yen – Spring 2010, alternative fuels combustion control
17. Keith Jones – Spring 2010 (ME497), VVA/PCCI research project
18. Scott Biggs – Spring 2010 (ME497), Summer 2010, modeling/estimation of piezo-electric fuel injection
19. Brandon Biller – Spring 2010 (ME497), Summer 2010 (SURF), Spring 2011 (ME497), VVA engine
20. Jin Shen (3+1+1 student) – Fall 2010 (ME497), Spring 2011 (ME597), Piezo-electric fuel injection

21. Yuntian Wang – Summer 2011, Fall 2011, Spring 2012, modeling VVA engine gas exchange
22. Mark Molewyk – Fall 2011 (ME497), piezo fuel injection experiments, Spring 2012 (ME497) VVA
23. Alex Wolfe – Fall 2011 (ME497), Spring 2012 (ME497) - VVA
24. Maximilian Harr – Fall 2011, modeling gas exchange for partial valve lifts
25. Derek Lee- Spring 2012 (ME497), fuel adaptive diesel engine control
26. Aswin Ramesh – Summer 2012, Modeling VVA engine gas exchange
27. Nandan Vora – Summer 2013
28. Austin Dollar – Spring 2013, Fall 2014, & Spring 2014 (ME497), modeling of SI engine
29. Sharang Kulkarni – Summer 2014, IIT-H exchange student, exhaust aftertreatment dynamic modeling
30. Brett Rasmus – Summer 2014, Fall 2014, VVA engine experiments
31. Xiaofan Guo – Fall 2014, Spring 2015, heavy-duty hybrid electric vehicle powertrain design/control
32. Troy Odstrcil – Summer 2015, SURF, CI engine efficiency improvements via VVA
33. Dina Caicedo-Parra – Summer 2015, SURF, CI engine efficiency improvements via VVA
34. Sree Harsha Rayasam – Summer 2015, IIT-H exchange student, heavy-duty HEV powertrains
35. Anant Dugar – Fall 2015, Data management from VVA engine
36. Julia Hartig – Spring 2016, VVA drive cycle data management
37. Neil Koglin – Spring 2016
38. Nianshen Zhang – Spring 2016
39. Xu (Sharon) Zhang – Spring 2016, Natural gas engine controls
40. Michael Crawford – Summer 2016, Enabling VVA engine drive-cycle testing
41. Erik Santini – Summer 2016 (SURF), CI engine efficiency improvements via VVA
42. Akanksha Baggan – Summer 2016 (IIT PURE), Modeling of battery thermal management
43. Conor Martin – Summer 2016 (SURF), In-cylinder combustion probe design
44. Harrison Senor – Summer 2016
45. David Ross – Fall 2016, Engine test data acquisition & viewing tools development
46. Yuhui Zhu – Fall 2016
47. Emerson Houck – Fall 2016
48. Nicholas Gaeta – Fall 2016, Spring 2017, Engine test cell & fuel consumption measurement design
49. Samir Solaiman – Spring 2017, VVA data management
50. Austin McDonald – Spring 2017, VVA drive-cycle data management
51. Joseph Wichlinski – Summer 2017 (SURF), Validation of a fuel consumption measurement device
52. Sirish Srinivasan – Summer 2017 (IIT PURE), VVA engine drive cycle analysis
53. Timothy Mueller, Jr. – Summer 2017, Engine testcell development
54. Miles Droege – Summer 2017, powertrain modeling; Spring 2018-Spring 2019, emissions measurement
55. Ehsan Esmaeili – Fall 2017, Enabling CAV engine testing
56. Urjayant Sangai – Fall 2017, CI engine efficiency improvements via VVA
57. Pablo Jimenez-Corredor – Fall 2017, Enabling CAV engine testing

58. Nachiket Vatkar – Spring 2018, Enabling emission prediction of HD PHEVs
59. Nishad Damle – Spring 2018, Spring 2019, VV aftertreatment thermal management analysis
60. Sean Franiak – Spring 2018, VVA engine modeling and analysis
61. Yifei (Bella) Ding – Spring 2018, Closed-loop control of engine boundary conditions
62. Manya Subbaramaiah – Spring 2018, Closed-loop control of engine boundary conditions
63. Conrad Lynch – Summer 2018, Truck Platooning
64. Sreenidh Sreekumar Praveena – Summer 2018, PURE
65. Harikrishnan Raghukumar – Summer 2018, PURE
66. Reese Holloway – Summer 2018, Spring 2019, Summer 2019, Engine testing for ARPA-E project
67. Ali Mandviwala – Fall 2018, High BMEP gasoline engine controls for PHEVs
68. Justin Rhines – Fall 2018, Spring 2019, Fall 2019 VVA/CDA in IC Engines
69. Urjayant Sangai – Fall 2018, Spring 2019, Engine testing for ARPA-E project
70. Harald Chao – Spring 2019, Simulation of novel control strategies for platooning trucks, and Fall 2019
71. Tamin Noor – Spring 2019
72. Adil Shaikh – Summer 2019, Control design, simulation & engine testing for advanced truck platooning
73. Scott Creger – Summer 2019 & Fall 2019 engine testing for advanced truck platooning
74. Aaron Villiger – Fall 2019, Variable Valve Actuation
75. Alexandre Fleisch – Fall 2019, Autonomous Truck Research

Current/Ongoing Research Projects led by Greg Shaver

Sponsor	per year approximate	research area	impact			# of graduate students supported	Industry, university or academic collaborators	Faculty collaborators	Staff collaborators
			fuel & CO2 reductions	improved safety	lower NOx & PM				
Cummins	$200,000	High efficiency, low CO2 natural gas engines	x		x	2.5	Cummins	---	Eric Holloway (CoE) Ryan Thayer (HLAB)
Deere	$800,000	Agricultural commercial vehicle automation & connectivity	x	x	x	5	Deere	Dan DeLaurentis (AAE) John Evans (ABE) Tony Vyn (Ag.)	---
Caterpillar	$150,000	Natural gas engine controls for power generation	x		x	2	Caterpillar	---	---
Dept. of Transportation via Joint Transportation Research Program	$230,000	On-road commercial vehicle automation & connectivity	x	x		2	Peloton Technology Cummins	---	Ryan Thayer (HLAB)
Dept. of Energy ARPA-E	$600,000	On-road commercial vehicle automation & connectivity	x	x		3	Peloton Technology Cummins	Neera Jain (ME) Darcy Bullock (ME) Dan DeLaurentis (AAE)	Ryan Thayer (HLAB)
Dept. of Energy	$150,000	Improving Efficiency of Off-Road Vehicles via Integration of Electric Machines and Advanced Combustion Engines	x		x	1.5	Univ. of Wisconsin Deere	---	---
National Biodiesel Board	$75,000	Optimization of high-blend biodiesel utilization in heavy-duty engines	x		x	2	Cummins	---	Eric Holloway (CoE) Ryan Thayer (HLAB)
ePower	$100,000	Experimentala & model-based assessment of split power series hybrid electric powertrains for class 8 truck	x		x	2	ePower	Oleg Wasynczuk (ECE)	---
Dept. of Energy US/China Clean Energy Research Center	$100,000	On-road commercial vehicle engine controls for plug-in hybrids	x		x	2	Cummins Freightliner Argonne Nat. Lab Oak Ridge Nat. Lab OSU & Michigan	---	---

per year approximate	$2,405,000

approx. grad student FTEs	22

Research funding details

- PI for $19,000,000 in funded research (~50/50 split between industry & government funding), of which:
    - $14,300,000 is for research on the Purdue campus
    - $12,250,000 is for research on the Purdue campus within Greg's research team.

Agency/Title of Grant: Cummins – Biodiesel Engine Research
Duration of Funding (mm/dd/yy – mm/dd/yy): 7/1/2007-12/31/2009
Total amount of award: $300,000
Your role and amount for which you are directly responsible: PI, $300,000

Agency/Title of Grant: ONR: Physics-based Modeling of Alt. Fuels Combustion in Diesel Engines
Duration of Funding (mm/dd/yy – mm/dd/yy): 8/7/2007-8/31/2010
Total amount of award: $435,000
Your role and amount for which you are directly responsible: PI, $435,000

Agency/Title of Grant: NSF: Modeling & Control of Multi-cylinder HCCI
Duration of Funding (mm/dd/yy – mm/dd/yy): 9/1/2007-8/31/2010
Total amount of award: $240,000
Your role and amount for which you are directly responsible: PI, $240,000

Agency/Title of Grant: Cummins - Variable Valve Actuation Engine Research
Duration of Funding (mm/dd/yy – mm/dd/yy): 10/1/2007-6/30/2010
Total amount of award: $400,000
Your role and amount for which you are directly responsible: PI, $400,000

Agency/Title of Grant: Cummins Fuel Systems
Duration of Funding (mm/dd/yy – mm/dd/yy): 10/1/08-2/28/2010
Total amount of award: $180,000
Your role and amount for which you are directly responsible: Co-PI, $90,000
Co-investigators: Peter Meckl (ME)

Agency/Title of Grant: Indiana Department of Environmental Management (IDEM) - Data Acquisition System Calibration and Emission Testing Tasks
Duration of Funding (mm/dd/yy – mm/dd/yy): 2/25/10-9/30/10
Total amount of award: $85,000
Your role and amount for which you are directly responsible: PI, $85,000

Agency/Title of Grant: Cummins - Cummins Fuel Systems Piezoelectric Fuel Injection System: Measurement, Modeling, Control and Virtual Sensing
Duration of Funding (mm/dd/yy – mm/dd/yy): 03/01/2010-02/28/2011
Total amount of award: $100,000
Your role and amount for which you are directly responsible: PI, $100,000

Agency/Title of Grant: Technology and System Level Demonstration of Highly Efficient and Clean, Diesel Powered Class 8 Trucks

Duration of Funding (mm/dd/yy – mm/dd/yy): 06/30/2010-05/30/2013

Total amount of award: $1,262,495

Your role and amount for which you are directly responsible: PI, $947K

Co-investigators: Robert Lucht (ME)

Agency/Title of Grant: Energy System Network – using funds from Department of Energy

Duration of Funding (mm/dd/yy – mm/dd/yy): 02/01/2011-04/30/2011

Total amount of award: $100,000

Your role and amount for which you are directly responsible: co-PI, $33,000

Co-investigators: Jim Caruthers (ChemE), Joe Pekny (IE)

Agency/Title of Grant: Cummins - Cummins Fuel Systems: Real-Time Estimation and Control of Rate Shaping for a Direct Acting Piezo-Electric Fuel Injector

Duration of Funding (mm/dd/yy – mm/dd/yy): 04/01/2011-03/31/2012

Total amount of award: $142,000

Your role and amount for which you are directly responsible: PI, $142,000

Agency/Title of Grant: Cummins/VVA System Upgrade

Duration of Funding (mm/dd/yy – mm/dd/yy): NA

Total amount of award: $238,000

Your role and amount for which you are directly responsible: PI, $238,000

Agency/Title of Grant: Department of Energy- EcoCar 2 Student Car Competition

Duration of Funding (mm/dd/yy – mm/dd/yy): 09/1/2011-08/31/2014

Total amount of award: $25,000

Your role and amount for which you are directly responsible: co-PI

Co-investigators: Meckl (ME), Motevalli (MET), Wasynczuk (ECE), Dietz (CIT)

Agency/Title of Grant: Department of Energy- Graduate Automotive Technology Education (GATE): Hoosier Heavy Hybrid Center of Excellence (H3CoE)

Duration of Funding (mm/dd/yy – mm/dd/yy): 10/1/2011-09/30/2016

Total amount of award: $1,000,000

Your role and amount for which you are directly responsible: PI, Director

Co-investigators: Maryam Saeedifard

Agency/Title of Grant: Cummins Inc – Adv. Power Electronics to Enable Plug-In Capability for a Heavy-Duty Hybrid Vehicle

Duration of Funding (mm/dd/yy – mm/dd/yy): 6/15/2012-5/31/2014

Total amount of award: $157,681

Your role and amount for which you are directly responsible: co-PI, $31,536

Agency/Title of Grant: Cummins - Cummins Fuel Systems: Real-Time Estimation and Control of Rate Shaping for a Direct Acting Piezo-Electric Fuel Injector
Duration of Funding (mm/dd/yy – mm/dd/yy): 05/15/2012-12/31/2013
Total amount of award: $271,124
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: Cummins – Enabling Ultra High Engine Efficiency via Flexible Valve Actuation
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2014-12/31/2018
Total amount of award: $1,500,000
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: Eaton – Enabling Ultra High Engine Efficiency via Flexible Valve Actuation
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2014-12/31/2016
Total amount of award: $750,000
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: Cummins – Model-Based Heavy Hybrid Vehicle Design Opt and Control
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2014-12/31/2014
Total amount of award: $25,000
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: Caterpillar – Engine Control Dev. for Stationary and Off-Highway Applications
Duration of Funding (mm/dd/yy – mm/dd/yy): 08/15/2014-08/14/2015
Total amount of award: $92,733
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: Caterpillar – Natural Gas Engines Control Project
Duration of Funding (mm/dd/yy – mm/dd/yy): 12/2015 – 11/2016
Total amount of award: $95,000
Your role and amount for which you are directly responsible: PI

Agency/Title of Grant: ARPA-E: High-Eff Control System for Connected and Automated Class 8 Trucks
Duration of Funding (mm/dd/yy – mm/dd/yy): 2/2017-1/2020
Total amount of award: $6,600,000 (25% cost share)
Your role and amount for which you are directly responsible: PI, $6,600,000 (total), $1,900,000 (Purdue)
Co-investigators: N. Jain (ME), D. DeLaurentis (AAE), S. Mou (AAE), S. Peeta (Civil)

Agency/Title of Grant: DOE/US-China Clean Energy Research Center (CERC)
Duration of Funding (mm/dd/yy – mm/dd/yy): 3/2017-2/2022
Total amount of award: $750,000 (25% cost share)
Your role and amount for which you are directly responsible: PI, $750,000

Agency/Title of Grant: Cummins/Power What's Next in Freight Transportation

Duration of Funding (mm/dd/yy – mm/dd/yy): 1/2017-12/2018
Total amount of award: $400,000
Your role and amount for which you are directly responsible: co-PI, $133,000
Co-investigators: N. Jain (ME), D. DeLaurentis (AAE)

Agency/Title of Grant: Eaton/Improving Diesel Engine Efficiency through Variable Valve Actuation
Duration of Funding (mm/dd/yy – mm/dd/yy): 1/2017-12/2018
Total amount of award: $500,000
Your role and amount for which you are directly responsible: PI, $500,000

Agency/Title of Grant: Caterpillar
Duration of Funding (mm/dd/yy – mm/dd/yy): 9/2018-8/2020
Total amount of award: $300,000
Your role and amount for which you are directly responsible: PI, $300,000

Agency/Title of Grant: Deere
Duration of Funding (mm/dd/yy – mm/dd/yy): 9/1/2018 – 10/31/2019
Total amount of award: $795,531
Your role and amount for which you are directly responsible: PI, $795,531
Co-investigators: Professors John Evans (ABE), Dan DeLaurentis (AAE), Tony Vyn (Ag)

Agency/Title of Grant: U.S DOT via INDOT/Purdue JTRP
Duration of Funding (mm/dd/yy – mm/dd/yy): 11/1/2018 – 8/31/2020
Total amount of award: $353,000
Your role and amount for which you are directly responsible: PI, $353,000

Agency/Title of Grant: Aramco/Pre-chamber Jet Ignition Research
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2019 – 12/31/2019
Total amount of award: $120,000
Your role and amount for which you are directly responsible: co-PI, $0K
Co-investigators: Professor Li Qiao (who is the PI)

Agency/Title of Grant: ePower/Testing Analysis and Simulation
Duration of Funding (mm/dd/yy – mm/dd/yy): 09/01/2019 – 05/10/2020
Total amount of award: $91,487
Your role and amount for which you are directly responsible: PI, $91,487
Co-investigators: Professor Oleg Wasynczuk (ECE)

Agency/Title of Grant: National Biodiesel Board/B21-B100 Performance Data and Emissions with Existing Engines
Duration of Funding (mm/dd/yy – mm/dd/yy): 10/01/2018 – 12/31/2020
Total amount of award: $74,206

Your role and amount for which you are directly responsible: PI, $74,206

Agency/Title of Grant: Dept. of Energy/Improving Efficiency of Off-Road Vehicles by Novel Integration of Electric Machines and Advanced Combustion Engines
Duration of Funding (mm/dd/yy – mm/dd/yy): 10/01/2019 – 09/30/2020
Total amount of award: $140,703
Your role and amount for which you are directly responsible: PI, $140,703

Agency/Title of Grant: Deere
Duration of Funding (mm/dd/yy – mm/dd/yy): 11/1/2019 – 10/31/2020
Total amount of award: $649,820
Your role and amount for which you are directly responsible: PI, $649,820
Co-investigators: Professors John Evans (ABE), Dan DeLaurentis (AAE), Tony Vyn (Ag)

Agency/Title of Grant: Cummins/Study of VVA Technology on a Stoichiometric Spark-Ignited Engine
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2019 – 12/31/2021
Total amount of award: $475,000
Your role and amount for which you are directly responsible: PI, $475,000

Agency/Title of Grant: Cummins
Duration of Funding (mm/dd/yy – mm/dd/yy): 01/01/2019 – 12/31/2021
Total amount of award: $200,000 gift
Your role and amount for which you are directly responsible: PI, $200,000

Patents: 6 active patent families, 2 issued patents (26 disclosures, 29 total applications)

APPENDIX B

CHARGE TO REVIEWERS

Technical Charge to External Peer Reviewers

Contract No. 68HE0C18C0001

Work Assignment No. 2-05

October 2020

External Peer Review of EPA's Heavy-Duty Technology Cost Report: Heavy-Duty Engine Valvetrain Technology Cost Assessment

BACKGROUND

EPA's *Heavy-Duty Engine Valvetrain Technology Cost Assessment* is a key milestone in an extensive effort being carried out by FEV, under contract with EPA, to estimate the costs of technologies likely to be used in meeting future heavy-duty highway vehicle criteria pollutant emissions standards, with a particular emphasis on technologies that reduce NOx emissions over a broad range of operating conditions. This report details the methodologies used by FEV and its subcontractor(s) to determine a cost for various heavy-duty emission control strategies and report the results of this work to date. **No independent data analysis will be required for this review.**

The Technology Cost Report identifies all component systems and subsystems and conducts an engineering evaluation/cost analysis of specific technology packages. These costs are heavily driven by engineering design choices and decisions that include projections of design, materials, and fabrication optimization potential for these technologies as they reach large-scale production.

The technology package was evaluated relative to a baseline technology for heavy-duty truck applications that is representative of the current state of design, and the baseline and new technology heavy-duty trucks having similar overall utility. For this study, EPA's contractor developed estimates for direct, indirect, and operating costs other than fuel costs. With respect to indirect costs, EPA's contractor estimated the incremental change in indirect costs for each sub-category of indirect cost which are projected to change as a result of the production of the new technology.

For this study, EPA's contractor evaluated the potential of, and projected costs for, the production of these heavy-duty truck technologies in the 2027-2030 timeframe. For promising technologies not expected to have fully matured within this timeframe, the evaluation was for the longer term (at full technology maturation-- high volumes, designs and fabrication processes optimized, initial R&D and capital investments recovered).

REVIEWER CHARGE

Specifically, EPA is seeking the reviewer's expert opinion on the methodologies being used in this cost work and whether they are likely to yield accurate results. Toward this end, EPA asks that each reviewer <u>comment on all aspects of the report, with particular emphasis on the costing methodology and sources of information used in determining labor rates, material prices, manufacturing burdens and other key factors</u>.

In preparing your comments, you should distinguish between

1. recommendations for clearly defined improvements that can be readily made, based on data or literature reasonably available to EPA, and
2. improvements that are more exploratory or dependent, which would be based on information not readily available to EPA.

Comments should be clear and detailed enough to EPA readers, or other parties familiar with the report, to allow a thorough understanding of the comment's relevance to material provided for review.

EPA requests that reviewers not release the peer review materials or their comments until the Agency makes its report/cost model and supporting documentation public. EPA will notify the reviewers when this occurs.