Light-Duty Technology Cost Analysis Pilot Study

Peer Review Report

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Prepared by:
ICF International

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Introduction

As the Environmental Protection Agency's (EPA) Office of Transportation and Air Quality develops its programs to control greenhouse gas (GHG) emissions from light-duty highway vehicles, there is a need to evaluate the costs of technologies likely to be used to meet these standards. EPA contracted with FEV, Inc., to perform this cost analysis through tearing down vehicles, engines, and components, both with and without these technologies, and evaluating, part by part, the observed differences in size, weight, materials, machining steps, and other cost-affecting parameters. Though complex and time-consuming, EPA believes this approach has great potential for determining accurate technology costs, a goal that is of paramount importance in the setting of appropriate GHG standards. EPA tasked ICF International (ICF), an independent third-party contractor, to conduct a peer review of the cost analysis now in progress to assure that this work incorporates the highest quality science.

Background of Peer Review

From August to October 2009, EPA arranged for ICF to conduct a peer review of the costing methodologies used by FEV, Inc., and its subcontractor, as detailed in the draft report, "Light-Duty Technology Cost Analysis Pilot Study" (FEV-07-069-103F, herein referred to as 'the Report'). ICF coordinated the peer review, adhering to EPA's "Peer Review Handbook" (3rd Edition).[1]

EPA's work assignment requesting the peer review required that peer reviewers be subject matter experts who have a general familiarity with manufacturing cost estimating, automotive design, or some knowledge of both.

Using these criteria, ICF developed a list of qualified candidates from the public, private, and academic sectors. ICF compiled candidates from the following sources: (1) ICF experts in this field with knowledge of relevant professional society membership, industry, academia, and other organizations, and (2) suggestions from EPA.

ICF identified 19 qualified individuals as candidates to participate in the peer review. ICF sent each of these individuals an introductory screening email to describe the needs of the peer review and to gauge the candidate's interest and availability. Also, ICF attached to the email a detailed conflict of interest (COI) disclosure. ICF asked all candidates to read the disclosure and disclose any real or perceived COI or other matters that would create the appearance of a lack of impartiality. ICF also asked candidates to provide an updated resume or curriculum vitae (CV). Several candidate reviewers were unable to participate in the peer review due to previous commitments, and several others did not respond. ICF reviewed the responses and COI statements and evaluated the resumes/CVs of the interested and available individuals for relevant experience and demonstrated expertise in the above areas, as demonstrated by educational degrees attained, research and work experience, publications, awards, and participation in relevant professional societies.

ICF reviewed the interested, available, and qualified candidates with the following concerns in mind. As stated in the EPA's Peer Review Handbook, the group of selected peer reviewers should be "sufficiently broad and diverse to fairly represent the relevant

[1] EPA/100/B-06/002

scientific and technical perspectives and fields of knowledge; they should represent a balanced range of technically legitimate points of view." As such, ICF selected peer reviewers to provide a complimentary balance of expertise covering the relevant economic and technical fields, including experts from industry, not-for-profit, and academic backgrounds. ICF submitted a list of the proposed peer reviewers to EPA, which EPA subsequently reviewed and approved.

ICF selected the following four individuals who agreed to participate in the peer review:

1. Dr. Dennis **Assanis**, University of Michigan
2. Mr. Sujit **Das**, Oakridge National Laboratory (UT-Battelle)
3. Ms. Laurie **Harbour**, Harbour Results, Inc.[2]
4. Mr. Wallace **Wade**, Ford Motor Company (retired)

In addition to the general COI screen mentioned above, prior to distribution of the peer review materials, ICF asked the four selected peer reviewers to complete and sign a COI disclosure form that addressed topics such as employment, investment interests and assets, property interests, research funding, and various other relevant issues. Upon review of each form, ICF determined that no peer reviewer had direct and substantial COI issues or appearance of a lack of impartiality. In addition, the peer reviewers were instructed to disclose to ICF any potential COI issues that may have arisen during their review, and no peer reviewer made such a disclosure.

ICF provided reviewers with the following materials:

- The draft report by FEV, Inc., entitled, "Light-Duty Technology Cost Analysis Pilot Study," dated September 3, 2009;
- Supporting spreadsheets detailing tear-down cost analyses; and
- A Peer Reviewer Charge to guide their evaluation.

Specific "charge" questions were not included in the Peer Reviewer Charge. Instead, EPA provided peer reviewers with general guidelines for preparing their overall review, with particular emphasis on the costing methodology and sources of information used in determining labor rates, material prices, manufacturing burdens, and other key factors. In addition, EPA asked each reviewer 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.

The charge to peer reviewers can be found in Appendix A. The original, complete comments as submitted by the peer reviewers are listed in Appendices B through E. The curricula vitae can be found in Appendix F. A list of acronyms is provided in Appendix G.[3]

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[2] In responding to the peer review charge, Ms. Harbour consulted with two colleagues at Harbour Results, Inc. (Harbour). As such, Ms. Harbour's comments in her submitted review (Appendix D) were written as coming from her team at Harbour. However, in this summary, we use 'Harbour' when referring to the comprehensive set of comments submitted by Ms. Harbour.

[3] Acronyms are defined at first use throughout this report, including in the reviewers' raw comments. No other editorial changes to the reviewers' comments have been made.

Overview of Peer Reviewer Responses

I. Organization of Reviewer Comments

The reviews varied widely in size, scope, and content. This summary of comments reorganizes the individual comments from all reviewers by theme and establishes common threads of reasoning. ICF organized the comments from the four peer reviewers into two main themes and sections of this report:

- Comments regarding methodologies and validation
- Comments regarding editorial content

Within each theme, relevant comments are presented, summarized, and attributed to their author. Subcategories are identified where appropriate from each major comment theme. For example, the methodological comments are broken down into comments generally regarding either study scope, inputs, processes, or assumptions (pre-processing and processing parameters) versus those regarding outputs or validation (post-processing parameters). Within each subcategory, any clear consensus reached by the various reviewers is emphasized, followed by any dissenting or unique comments.

Some comments addressed multiple items. For example, many comments referred to unclear statements, which could be due to a flaw in the methodology and/or insufficient explanation. In these cases, the comment is placed where it seems most appropriate. In all cases, comments are attributed to the author by the name listed in bold in the numerated list above (e.g., Assanis).

Each reviewer organized and provided his or her comments in the following ways:

1. Assanis presented comments in a five-page text file. His comments are organized into the following three sections: summary, organizational, and detailed technical comments.
2. Das presented his comments in a four-page text file and as a numerated list, unorganized by theme or report section.
3. Harbour presented her comments as both an eleven-page summary text file and 94 additional comments within a spreadsheet. The spreadsheet generally contains comments directed to a specific element of the Report and cited by page or section number. The summary text file contains more general comments. In both cases, the comments are grouped into one of the following seven “classifications”: Technology, Premise, Methodology, Protocol, Operational Definition, Statistical Validity, or Presentation. A General Feedback section is also presented.
4. Wade presented detailed comments in the following three sections: an overall review, specific opinions and recommendations, and discussion. The latter two sections focused on eight primary opinions and recommendations for the Report. His eight primary opinions were summarized in the second section, then repeated and expanded upon with editorial comments in the third section. (Before summarizing, ICF merged the latter two sections.)

In all cases, ICF mapped each individual reviewer comment to one of the two main themes. In cases where the comment could apply to either theme, ICF made a judgment on which topic it most closely represented and included it under that theme.

II. Methodological Comments

a. Comments Regarding Study Pre-Processing and Processing Concepts

Comments Regarding Study Scope

All reviewers noted that the study was well focused and praised the use of case studies. However, all reviewers also noted specific issues with the present case study, the potential scaling methodology, and/or future case studies. Assanis, Das, and Harbour were specific about this. Their comments follow.

Harbour noted that the study becomes complex so quickly that the user could lose sight of the bigger issues and challenges posed by such a technology shift, although she appreciated the use of the methodology presented to improve the accuracy and reliability of its economic impact studies. Specifically, she noted that her clients have been historically at odds with EPA forecasted impacts and costs and are hopeful that this study will alleviate some of these concerns. However, she noted a significant difference between historical EPA forecasts and industry's assessed costs. Harbour also expressed concern that the scope of the study will dictate the level of assumptions and data required. She noted that the big questions, such as whether the scope regards only replacing 2.4L with 1.6L engines or extrapolating these results to other future engine technologies, will impact the study's scope.

Assanis expressed specific concerns regarding the future technologies slated for study. He noted that, of the powertrain technologies identified for evaluation, some are advanced versions of current powertrains, such as downsized turbocharged gasoline direct injection (GDI), advanced diesel, and advanced transmissions, while others, such as homogeneous charge compression ignition (HCCI) and lean-burn GDI—while still predominantly mechanical powertrains—will involve new challenges in electronics, calibration, and catalytic after treatment that may not be addressed by the study in its current state. He also notes that flexible/alternative fuel powertrain packages are omitted from the current scoping list. Finally, regarding the future technology groups, he noted that the proposed technologies are quantized into discrete bins, when in fact production hybrid versions are likely to be available soon, such as GDI engines with operation split between the lean stratified and homogenous stoichiometric modes varying by required power. He noted that the current scope may thus need to be modified to treat technology combinations, such as GDI/HCCI hybrids, and that the time horizon, manufacturing, research and development (R&D) and calibration costs for some technologies (such as for camless versus cam profile switching/ phasing and mechanical lift control) will depend on their implementation.

Das stated that, while the bottom-up approach with detailed cost estimation based on teardowns of vehicles implemented in the study is an improvement over past analyses, based on supplier price quotes for key components, the scope may have limited success for new technologies. He also noted that the scope is prohibitively expensive and time-consuming for regular use, unless an appropriate scaling methodology is developed.

Comments Regarding Study Assumptions

Das, Harbour, and Wade all expressed concerns regarding production volume assumptions. Specifically, Harbour challenged the use of 450,000 single unit volume, as opposed to five units of annual volume 80,000 to 90,000, as the basis for estimations. She expressed concern that this approach may significantly understate the total amount of amortized fixed costs in supplier pricing. Further elaboration on the basis of her breakdown is given in her full comments in Appendix D. Wade noted that the selection of vehicles that represent the base and new technology cases for the teardown and cost analysis could have different production volumes and that higher volumes for a new technology may result in different design and manufacturing techniques, and thus impact costs. The assumed 20,000 units per year production volumes of the new technology engine versus 840,000 for the comparator baseline could affect costs in the present analysis and even more for future analyses, such as lithium-ion batteries. Das stated that 450,000 units assumed for a robust market penetration rate may not be the same across various technology types if numerous suppliers are involved simultaneously because the present cost estimation is based on an individual tier-level supplier. Rather, varying annual production volume should be included.

Das, Harbour, and Wade expressed concerns regarding specific cost assumptions. Harbour noted that, while a detailed “bottom-up” cost analysis is an essential part of the estimate of the impact of technology changes on the marketplace, the Report does not adequately identify economic and marketplace assumptions. Wade commented that different levels of maturity may be represented in the new technology versus the base comparator technology, which could bias the cost estimates. He also noted that no added vehicle costs were considered for the pilot study new technologies, although new technology is likely to require new or different vehicle installation hardware and the associated costs and should be included in the overall costs. Finally, he stated that intellectual property, and the costs associated with licensing, patents, know-how, and trade secrets, which is often an important part of new technology powertrains, seems to be assumed to not affect costs and/or was not addressed in the methodology. Similarly, Harbour noted that the Report needs to be explicit in assuming where current original equipment manufacturers (OEM) and supplier manufacturing equipment and facility capabilities are insufficient because, should demand for certain technologies exceed supply, OEMs will be forced to pay a premium for these parts. She considered assuming sales below capacity for modeling incremental costs to be specious. Das noted that, while consideration of maintenance and end-of-life costs are given, the assumptions and approach regarding these costs are insufficiently detailed and appear subjective. Finally, Das questioned the assumed 0.3%-0.7% total manufacturing cost (TMC) for end-item scrap markup.

Assanis noted that, given the recent turmoil in the North American automotive industry (both OEMs and suppliers), the assumed structure of labor wages and rates, based on historical rates (e.g., fringe rates based on a 2006/2007 average United Auto Workers (UAW) OEM wage and labor rate) may no longer be appropriate. Also, concerning the assumed labor mix and associated costs, Wade stated that the decisions to use either OEM or suppliers for manufacturing specific components is not clearly explained but appears to be based on conventional practice and/or input from experts. However, since OEM labor rates are significantly higher than supplier wage rates, these assumptions can significantly affect overall costs and should be clearly explained.

Wade and Harbour questioned the assumed technology and part supply chain. Wade noted that OEMs and suppliers are assumed to have the manufacturing facilities and equipment for the new technologies, but components comprising the core of the new technology will probably be incremental and require new manufacturing facilities and equipment. While the Report assumes that OEMs and suppliers have manufacturing equipment and facilities capable of handling required manufacturing processes and capacities, this assumption may not be valid in most cases. He stated that while all manufacturing processes and operations are assumed to be based on standard/mainstream industrial processes, new technology is likely to involve unique, new, non-standard industrial processes, especially in the battery area, which do not seem to be accounted for in the Report. He further noted that different internal design and manufacturing practices may be represented in new technology if from different manufacturers, and thus rely on different internal practices that are not captured in the present assumed methodology. Harbour commented that, contrary to present assumptions, use of off-shore suppliers may not by default reduce costs due to increases in freight costs, tariffs, unmeasured internal supply/program management resources, and exchange rate changes. Wade noted that warranty data on new and baseline technologies should have been examined to validate assumptions on design methodologies and ensure comparable useful lives because high warranty costs for the new technology would indicate inadequate designs, materials, or processes. Finally, Harbour questioned the selection of projection years (2015 and 2020) and whether assumed technologies will be leading edge then.

Comments Regarding Study Inputs

All reviewers provided specific comments addressing various study input parameters. Regarding the Annual Adjustment Factor (AAF), Wade stated that a serious discrepancy between Figure 6 and Appendix E must be resolved before the Report is published. Although Figure 6 shows an AAF of –5% from 2008 to 2015, Appendix E lists an AAF of 0%, which will affect results. Harbour also noted this parameter and claims that a 5% per year decline in supplier labor rates is inappropriate given inflation, generally increasing labor rates in the manufacturing sector, and the distinction between declining labor rates and declining labor content due to process improvements. Harbour further noted that Design Profit® might assume that the part will be manufactured in the leanest possible way in year one, which is inconsistent with the assumed 5% reduction.

Harbour commented that the manual input cost parameters are sound and the study does an exceptional job accounting for part variability. She also said the logic applied to material identification is sound, but added that consideration should be given to whether a mistaken material selection would be financially material. She also recommended that the study add classifications in Manufacturing Assumption and Quote Summary (MAQS) to manufacturing operations as either lean or mass, and be prepared to sort results accordingly to explore resulting cost differences, given that the industry could experience higher batch processing costs than those estimated by the model.

Das and Harbour commented on the inputs accounting for markup. Harbour noted that engineering, design and testing (ED&T), scrap, and selling, general, and administrative (SG&A) mark-ups all appear arbitrary and should be justified and validated through a sensitivity analysis. Das stated that it may be inaccurate to apply the same level of mark-up regardless of the primary manufacturing process and equipment groups involved. Variations in company size, part complexity, and manufacturing technology type and their impact on final mark-up rate should be included in the calculations. Finally, Das noted that, if the cost methodology is based on Vyas et al. (2000), then the end-item scrap mark-up includes mainly the warranty cost, but is used in this study as if it also includes in-process scrap. He stated that this should be grouped with manufacturing overhead rate parameters to better reflect technology characteristics.

Das, Harbour, and Wade all commented on wage and salary inputs. Harbour noted that the active rates (Figure 12) and rates (Figure 13) appear arbitrary and not derived. Das questioned why the OEM fringe rate is more than three times higher than for tiered supplier manufacturing, while Wade noted a discrepancy in the projected labor rates used for 2015 that should be corrected.

Comments Regarding Study Methodology

All reviewers commented favorably on the study's general methodology. Wade, in particular, noted that FEV has developed and applied a detailed, objective methodology for determining net incremental/assembly cost impact to the OEM for new technology powertrains with reduced GHG potential. He said this methodology will both provide EPA with the capability to estimate the cost of technology to meet regulations as well as act as a medium for EPA to interact with OEMs and suppliers to review, compare, and rationalize their costs. However, he noted that while the methodology ideally should yield accurate results, he found potential issues with the methodology that may affect the accuracy of the results. In particular, he noted that during the conference call it was indicated that three specific, important steps described in the methodology (a marketplace crosscheck, accounting for design modifications for Material Cost Reductions (MCR), and accounting for New Technology Advances (NTA)) were not being followed, and that these should either be followed or removed from the Report. Each step is detailed in Appendix E, Opinion #7 of this summary report. Das noted that the methodology presented, using a standard quoting template used by the automotive industry for the MAQS, is an excellent approach and deserving of credit. Harbour stated that the overwhelming majority of methodologies employed in this study appear to be sound and, in particular, she approved of the use of activity-based burden rates, machine-based burden rates, and AAF. She also generally approved of the differential analysis logic, but questioned the statistical basis for assuming differences in means between baseline and new technologies. She recommended that the methodology be adjusted such that any proposed technology changes are classified into one of the following four distinct categories of R&D investment and that a total cost versus incremental cost model for these changes be developed: new product development, fuel economy improvement and emissions, pure research, and plant energy and emissions.

Assanis noted that the topic is both an important one and a difficult one for arriving at a universal methodology, but that it should be recognized that the proposed methodology focuses more heavily on tracking component materials and manufacturing costs and less on system integration issues and costs, which are typically captured through indirect cost multipliers. He felt that for new powertrain technologies that are evolutionary versions of current technologies, the methodology has the potential to produce fairly accurate estimates of final costs, but as components and systems become different from current versions, both the manufacturing and systems integration aspects of this methodology will be challenged.

Harbour and Wade questioned the methodology dealing with unit volume. Harbour questioned whether the vehicle class summary was used to identify target vehicle platforms that would likely adopt the new engine technology and set expected volumes. She found 450,000 units to be unrealistically high. Similarly, Wade commented that the analysis assumes annual volume of 450,000 units, the basis of which should be provided, and which may be inconsistent with the recent severe fluctuations in the automotive market. He requested that volume-sensitive costs be provided and the methodology be made flexible to the impact of severe fluctuations in the automotive market, which could possibly affect the accuracy of the cost estimates.

Wade, Harbour, and Das provided other specific comments regarding the process used. Wade noted that production testing (e.g., on fuel rails) and end-of-line testing may be required for some components or systems but is not addressed in the methodology. Harbour stated that the process mapping is sound but manufacturing practices that are less than optimal should be addressed by clearly distinguishing between batch and lean and possibly a sensitivity analysis showing a mix of practices that are more “batch” oriented. Das noted that the linkage between primary fabrication processes and secondary cost estimating modules is unclear. Finally, Wade commented that the visual teardown inspection used cannot capture many detailed specifications used in the manufacture of the part, such as tolerances, surface finishes, or flatness requirements that could add additional cost to the parts. However, these processes do not appear to be included in Design Profit.

Harbour and Das provided opposing views on the general use of software in this methodology, although both expressed concerns. Das noted that the cost estimation approach becomes “fuzzy” after the Lean Design® software converts serial processing operations into mass production operations. This process is not at all transparent, at times an ad-hoc procedure is used, and it requires subjective judgments along the way. He also expressed concern that the material usage “lb” variable is automatically uploaded from Process Mapping instead of a user input. However, Harbour commented that she has already experienced Design Profit technology in prior projects and is confident in its valid integration of product design, manufacturing processes, and associated demand, cycle time, labor, material, costs, and forecast data. However, she expressed concern that Design Profit uses a static treatment of data, whereas other simulation software dynamically models manufacturing behavior and may provide a better understanding of cost variances over time. She also noted that Design Profit is costing on ideal designs and manufacturing flows that may make costs appear lower.

Wade, Das, and Harbour all noted potential inconsistencies in the costing methodology. Harbour stated that the cost database integration and automatic updates to "active Rates" is exceptional, and that the logic used for shipping costs, investment cost as part of manufacturing overhead, product development costs, and tooling cost allocation are sound. However, she said it is unclear how/if unique investment costs are included or referenced and how forecasting of future prices are extrapolated from limited input. Wade commented that the Comparison Bill of Materials (CBOM) chart includes a provision for accounting for design modifications for material cost reduction (MCR), but noted that during the conference call it was indicated that this was not done. Das expressed uncertainty about whether the Munro & Associates costing software also is used for secondary processes, since mapping of these processes using Design Profit software is indicated in the text but not in the costing procedure. Further, he noted that it is unclear how tooling and investment assumptions are incorporated into the part cost estimation, and how tooling is different and estimated as a part of the indirect cost (IC) multiplier of the OEM and as manufacturing overhead. Finally, he noted that, while the inclusion of MCR and NTA assumptions in the CBOM is an excellent option that should be used more frequently to project future cost reductions with technology maturation, it is unclear how these have been implemented into the overall cost estimation procedure.

All reviewers provided comments on the methodology used for markup costs. Assanis noted that the calibration of multi-variable, high degree of freedom systems can require more resources and time than their direct manufacturing costs, although the availability of historical cost databases for relevant components of advanced technology vehicles is very limited. Because of this, the related R&D and calibration issues would not be captured well by currently used IC multipliers. This will become more significant with other technologies, such as electric vehicles. All other reviewers found the need for more clear application of the IC multiplier report. Harbour noted that many of the premises set forth in the IC multipliers report apply here and should be incorporated. She also noted that active rates and mark-ups appear arbitrary and not derived. However, she saw no major flaws in the IC multiplier logic, the logic for ED&T mark-up, end-item scrap mark-up, SG&A mark-up, Tier 2 and 3 supplier mark-ups, and profit mark-up. However for the profit mark-up, she said it is unclear where proprietary or unknown materials are used as well as the value of the impacted component in achieving more desirable emissions. Das noted that IC has not been applied consistently, particularly as the IC relates to a Tier 1 vendor. This is noted repeatedly where an OEM has been used as the supplier, but no indirect cost multipliers (ICM) are incorporated. He found that the concept of IC multiplier is mentioned several times in the document, but no specific applications of the actual data are found. More of his specific comments regarding this are included in Appendix C. Similarly, Wade stated that the recent ICM study should be applied to capture the overall price for new technology because the present methodology generally is designed to determine incremental, direct manufacturing costs for new versus baseline technologies.

Wade and Harbour provided additional, specific comments on the methodologies used for technology analysis. Wade stated that the CBOM chart shows potential accounting for NTA – which could provide alternative, advanced technology ideas as a potential substitute for some existing hardware being evaluated – but that on the conference call it was indicated that this was not done. He further noted that differences between components contained in both the new technology and comparator baseline but not directly related to the technology may need to be analyzed to determine the proper handling of these differences. Wade commented further that although the report states that "…application of new technologies in five vehicle size classes is considered," no details are provided and that the methodology would require, for each of the five vehicle size classes, a detailed analysis to account for significant change in the engine configuration for larger engine sizes. He also concluded that the analysis of the port fuel injection (PFI) powertrain control module (PCM) cost is insufficient (see detailed comments in Appendix E). Harbour questioned how an engine with new or proprietary materials and physical designs can have no change in maintenance or end of life costs. More significantly, Harbour stated that industry may push back on the general assumption that a product technology is mature, or is something that would have been invested in any case, especially if EPA regulations mandate significant emission reductions over currently planned R&D efforts. She noted that a survey of industry to validate the maturity of various technologies and estimate the amount of R&D should be built into the suppliers' price.

Regarding component materials and suppliers, Wade and Das found the methodology somewhat lacking, while Harbour generally was pleased with the approach. Wade stated that the method for determining the required material weights for the manufacturing processes, which would be higher than the finished part weights found in the teardown process, was not explained in adequate detail. In particular, material cost appears to be derived by multiplying the component part weight by the material cost per weight, which ignores metal removal or casting waste. He noted that further explanation of the methodology to determine material weights and the overall size of the part in bar or rod form should be explained. Wade also commented that the use of the cross-functional review team is not a rigorous method for determining material used in a specific part from a teardown. Instead, a more reliable method, such as conducting an analysis of the actual material from the part, should be used. Das found that subjective expert judgment is necessary for the material selection process for the unmarked materials. Harbour stated that sound logic is used for commodity-based purchased parts, primary equipment groupings in Table 2, unknown proprietary material compositions, and in the use of marketing firms to trend future prices as compared to similar material trends. However, she noted that consideration should be given to why proprietary materials are typically used to offset other lifecycle costs when proprietary materials typically increase start-up and validation costs. She also commented that the material identification methodology is sound and demonstrates real industry knowledge.

Both Das and Harbour commented that the methodology treating packaging cost is adequate. Harbour stated that sound logic was used for packaging selection and costs. Das noted that the attention paid in the estimation of packaging cost is good, but possibly not worth the consideration because its contribution to the net incremental unit part cost may not be as significant as compared to other cost categories.

Harbour, Das, and Wade all commented on the methodological treatment of wages. Harbour found that there was insufficient information to determine how the analysis forecasts the union versus non-union labor mix for future dates and recommended a sensitivity analysis on this parameter. She found that the logic for calculating and applying indirect labor ratio is adequate, as is the logic for calculating the labor rate, although it was unclear how the median wage rate is used and how it impacts the Report findings. Das agreed that the labor rate estimation approach is sound and based on a reliable public data source. However, Wade noted that using labor rates based on the described labor mix may result in significant errors in labor costs from applying a mixed labor rate to a fully unionized supplier or, conversely, a non-unionized supplier. He said further justification is needed, especially following the severe restructuring in the automotive industry in 2008 and 2009. Wade further noted that the 2006/2007 fringe rate burden data for OEMs may be obsolete as a result of the many recent changes in the automotive industry and should be updated.

Regarding other factors that may be considered along with the cited results, Harbour stated that other design features, such as aerodynamics, rolling resistance, type of fuel, and weight also work in combination with the engine technology to achieve emission levels, and should be considered along with engine technology. She also found it unclear whether vehicle classification is useful in determining the potential application of the 1.6L engine and its competitive alternatives. Wade noted that the comparison of fuel economy for the new technology and comparator baseline vehicle is flawed because the new technology is applied to a significantly lighter vehicle. Additionally, he noted that the methodology does not appear to account for the costs required to reduce emissions of the new technology to the level of the baseline, including costs required to ensure comparable certification emission levels for the new technology.

b. Comments Regarding Study Outputs and Validation

Comments Regarding Study Outputs

Only Harbour provided comments regarding the grouping and analysis of study outputs. She presented three primary recommendations. First, she recommended that various parts identified in the CBOMs be classified by their known or projected impact on emissions so industrial and consumer costs can be attributed to performance capabilities, as expected for a value engineering study. Second, she recommended that a list of torque variables be developed and ranked by their financial impact and their impact on lowering emissions. These are parameters that can greatly influence the financial materiality or discernable improvements in emission levels, such as engineered items and union labor content. Third, she recommended that a list of uncertainty factors be developed, that uncertainty analysis be used to validate other proxies of prices, and that results be indexed to the price models.

Comments Regarding Study Validation

Wade and Assanis requested that minor validation steps be taken on the study's results, but Harbour requested a more significant review and validation of the study. Assanis requested a sensitivity assessment of the results to the assumption of an average volume of 450,000 units. Wade noted that the methodology described subjecting a part with high or unexpected cost results to a marketplace crosscheck for validation, but that this had not been performed. He stated that this is a critical step for validation of the results, especially for the four high cost items. Harbour noted that a statistical expert review needs to be added as a final step to validate that the resultant costs are indeed statistically different for materials, labor, and combined into direct manufacturing costs. She said, in all cases, data used for comparison needs to be described by at least a mean and a standard deviation to establish if proposed average costs of the new engine are within the price variations assumptions of the baseline engine. An assessment also needs to be made of whether future prices will have the same variation between the baseline and new engines. Harbour also requested a sensitivity analysis on the different classifications discussed in Table 3 and to include changes in arbitrary weighting factors. If the regression analysis in Figure 9 is of price averages, Harbour noted that a statistical test of homoscedasticity is needed to validate the weightings. Harbour also called for an uncertainty analysis for ill-defined or unknown materials, manufacturing, and procurement practices that materially affect cost outcomes in addition to the sensitivity analysis. She said the uncertainty analysis should validate other proxies of prices, such as raw material cost trends and exchange rate fluctuations, then subsequently index them to the price models used. Finally, Harbour stated that uncertainty factors should be aligned to torque variables and ranked to their impact on lowering emissions.

III. Editorial Comments

a. Comments on Organization and Pagination

Generally, the reviewers considered the Report presentation to be adequate. Harbour stated that the flow is logical.

Assanis noted that page numbering is confusing. Das noted that in Section 5.0, "material costs include a combination of raw materials, material processing scrap, and commodity purchased parts," but material cost is discussed in Section 6 and material processing scrap has been included under "End-Item Scrap" based on the methodology described in the document – he said this organization should be improved. Harbour noted that parts should be classified as repairable or replaceable and this should be included in the organization, since this affects the consumer's cost of ownership.

Wade and Assanis presented two specific organizational comments. Wade noted that to evaluate the validity of the overall methodology, information needs to be added regarding the software and databases with respect to 1) what the software does, 2) how embedded data in the software or the databases were developed, and 3) how the software or databases have been validated. Assanis stated that the Report relies on presenting the proposed methodology in tandem with the case study, but references a large number of spreadsheets and databases in appendices that obfuscates the presentation of the general methodology in the body of the Report. Although he approved of including in the Report a comprehensive case study, he said the presentation of specific examples is too lengthy while other sections, particularly those where key methodological assumptions are presented, are too laconic. He stated the draft generally needs to be reorganized and provided a suggested structure, which is presented in his full comments (Appendix B).

b. Comments on Grammar and Wording

Reviewers provided the following typographical edits:

- Pages 1-3: there is a typo in the Flowchart. "Cross Fucntion" should be "Cross Function." (Assanis)
- Pages 4-5, 4th paragraph: "To accomplish this" needs to be followed by a comma. (Assanis)
- Page 5.2, the first line: "…are involved…" has an extra period. (Assanis)
- Pages 6-7: the last line "Annual Adjustment Factors" should be corrected to "Annual Adjustment Factor." (Wade)
- Page 31: the last line: "…in the cast study analysis." should be changed to "…in the cost study analysis." (Wade)
- Page 35, Section 6.2.3: line 6: "…Metalprices, estainlesssteel…" should be changed to "…metal prices, stainless steel…" (Wade)
- Page 36, Section 6.2.4, paragraph 2, line 1 and Figure 9: "Figure 9 illustrates the power curve…" should be changed to "Figure 9 illustrates the price curve…" (Wade)
- Page 45, line 1: "…establish the reference the baseline…" should be changed to "…establish the reference baseline…" (Wade)

- Page 52, line 2: "…same level of mark-up is applied regardless the…" should be changed to "…same level of mark-up is applied regardless of the…" (Wade)
- Page 58, last paragraph, line 4: "…manufacturing costs are capture for the…" should be changed to "…manufacturing costs are captured for the…" (Wade)
- Page 58, last paragraph, next to the last line: "Alternatively in single a MAQS…" should be changed to "Alternatively in a single MAQS…" (Wade)
- Page 61, first paragraph under Section 9.3, line 4:"…interactions tacking place…" should be changed to "…interactions taking place…" (Wade)

Reviewers provided the following suggestions to provide clarity and consistency within the Report:

- Page 4.5, 3rd paragraph: "Most all of the processes" needs rewriting. (Assanis)
- Pages 4-5: the factoring methodology used to deal with part variability needs more description. (Assanis)
- Page A-0, section 3.1: The statement that no new technology was considered between a naturally-aspirated I4 and a downsized turbocharged engine is confusing. (Assanis)
- Page 13: The convention adopted in this report of referring to a "quote" as the "analytically-determined cost of a part or assembly, not a price provided by a supplier", is misleading. Common terminology is that a quote is a price provided by a supplier. An analytically determined cost should be called an "analytically determined cost" in the Report. (Wade)
- The authors should better define and be prepared to defend the "judicious scaling" protocol used. (Harbour)
- Modules, top level components, end-item components, parts, are introduced as new terms in the system hierarchy, but could be better written to use generic terminology. (Harbour)
- The Report uses mixed and confusing definitions of system/subsystem/high level modules/modules/top level components/assemblies/components/end-item components/piece parts/parts hierarchies. The author often uses multiple terms to describe the same part. Generally, the hierarchy needs to be defined and consistently used throughout analysis. (Harbour)
- The subsystem, sub-subsystem, assembly, subassembly, component are all well stated, but the Report does not read this consistently. Also, it is unclear if levels change as data is entered in Design Profit. (Harbour)
- The term "high level modules" is introduced as part of the Design Profit nomenclature. (Harbour)
- While there is an excellent distinction between MCR and NTA, a better operational definition is needed. (Harbour)
- The distinction between Lean Design and Design Profit needs to be clarified. (Harbour)
- The statement "annual consumption rate which impacts whether high or low volume prices are used" is unclear regarding whether a nominal or mean rate is also used (or just high or low?). (Harbour)
- A definition of financial materiality is needed. (Harbour)
- The authors should clarify what method is used for the investment cost depreciation over the production volume in the estimation of manufacturing overhead rate. (Das)

- The authors should clarify whether there are known variances in the active rate and if/how these are accounted for in determining either statistical differences and/or financial materiality. (Harbour)
- While the work assignment focuses on the determination of incremental direct manufacturing cost, a solid definition of direct manufacturing costs should be added. (Das)
- The five vehicle classes considered should be mapped to the 13 EPA vehicle classes {49 CFR part 523}. (Das)
- The variable OEM/T1 Classification in Appendix G should be uniformly added to the subsystem worksheets. (Das)
- A glossary of terms should be provided. (Wade)
- Each of the appendices should be listed in the Table of Contents (Wade)
- An operational definition of high and low volumes; high impact purchased parts, low impact purchased parts and commodity parts; standard/mainstream industrial practices; and how parts were deemed to be excluded should be added. (Harbour)
- The authors should clarify whom or what validates NTA's "fitness for use." (Harbour)
- A representative formula should be given that describes the use of input factors, following the first paragraph of Page 4-6. (Assanis)
- An explanation of "composition analysis plus surcharge" should be provided. (Wade)
- For ease of cross-referencing, the numbering used for the subsystems throughout the analysis should be used on the summary chart showing the incremental costs. (Wade)
- In numerous cases, instead of citing a published reference, recourse is made to a consultation between EPA and FEV, or feedback from a subject matter expert without presentation of ranges and sensitivities considered, and a discussion of where the estimate selected for this study fell within the range. (Assanis)
- Clarification is needed on the protocol employed to determine if differences in emission benefits and cost factors, for base versus new components, are worthy of industry investment and consumer investment. (Harbour)
- While "Component level quotes" are logically classified as full quote, modification quote, and differential quote, operational definitions should be added for each with clear examples. (Harbour)
- The Report should be explicit in where current OEM and Supplier manufacturing equipment and facility capabilities are insufficient. (Harbour)

c. Recommended Content to be Added

In addition to the specific itemized changes listed above, reviewers made numerous comments regarding the need for additional material in some sections.

Assanis noted that, in general, there should be more discussion of the results presented in figures, tables, worksheets, and more critical assessment of results, rather than just summarizing the results in a table or figure, and more discussion of uncertainties present in the analysis along with specific findings. For example, in Section 5, page A-0, a section on IC multipliers is needed to summarize key findings of the companion EPA study, along with a discussion of areas where improvement to that methodology needs to be made to deal with the R&D and calibration costs of some of the new technologies (especially high complexity, disruptive electrical technologies).

Regarding use of databases, Das noted that annual consumption rates and source references to the materials database are not listed in Figures 7A and 7B and that the material price needs to be referenced to a specific production volume with indications of the volume sensitivity factor. Although the electronic database contained some of the information, he said the report text should be clarified. Wade noted that the databases for material costs, labor rates, manufacturing overhead rates, mark-up rates, and packaging costs provide the foundation of the cost analysis, but were not adequately addressed in the Report and were not provided for review with the original package. Furthermore, he noted that descriptions of how the proprietary software and databases were validated, which would be required to determine the accuracy of the cost estimates, are not included. Wade also state that while parts considered a "buy" and "surrogate costs are pulled from an applicable database" there is inadequate description of this "applicable database," including how it was developed and how it was validated. Further, Wade noted that Appendix G states that a "Purchase Part Database" is used to provide values for commodity purchased parts, but it is unclear if and how this database differs from the "applicable database." Generally, he said the methodology makes extensive use of proprietary software and databases, which are not available for peer review. Without detailed information regarding these proprietary tools, especially Lean Design, Design Profit, "An applicable database" for surrogate costs, and the "Purchase Part Database," the accuracy of the cost estimates cannot be determined. The Report needs to clarify how these four software and databases are related.

Reviewers also provided comments regarding Design Profit and Lean Design. Assanis noted that its description is too superficial, even considering Figure 2. The key assumptions and algorithms of the methodology need to be presented, and a discussion of the mapping process needs to be included in Figure 2. Wade noted that more information is needed on the details of Design Profit, especially how it determines the times required for each step of the process, how the software results were validated, and to clarify how the Lean Design input to the MAQS differs from the Design Profit input into the MAQS. Das stated that the manufacturing assumptions section, positioned to the right of the quote summary section in MAQS, is where the additional assumptions and calculations are made to convert the serial processing operations from Lean Design into mass production operations, but inadequate information is given regarding the underlying assumptions and calculations. Harbour stated that having a consistent hierarchy and part naming between spreadsheets, Design Profit, and the Report would add value. Assanis noted that several critical assumptions of the methodology are not presented in the Report, but instead are left to reference the proprietary software Design Profit. While recognizing the need to protect proprietary intellectual property, he said the basic assumptions, math, and algorithms should be described in the Report to give the reader a basis for judgment without giving away sensitive cost figures, etc. Harbour noted that a more detailed diagram is needed to show the flow of information into and out of the MAQS worksheet, especially regarding mark-up levels shown in Figure 14. Finally, Harbour commented that a data architecture diagram indicating which secondary cost estimating modules, Munro cost databases, etc., are used and how they feed into Design Profit, would be useful to put forth premises, arguments, and conclusions for future EPA regulations. She also said all data sources should be validated statistically with hypothesis stated regarding differences between base and new technology.

All reviewers requested clarifying information regarding overhead and labor costs. For example, Wade noted that "the Applied Burden Rate generally results in labor costs that are many times higher than the direct labor costs," however the derivation and validation of the values used in the equation for calculating Applied Burden Rate were not clearly described in the Report. Since the Applied Burden Rate has a major influence on the overall labor costs, he said the lack of adequate detail regarding the values used to calculate the Applied Burden Rate is a concern and could potentially affect the accuracy of the cost estimate. Harbour noted that acquiring Manufacturing Overhead Data is the most nebulous part of the Report and that more explanation of sources is needed to support numbers. Das stated that estimation of manufacturing overhead rates is one of the critical elements to the overall cost estimation process – it is dependent on many parameters but the database neither indicates the estimation procedure nor its underlying assumptions. Pages 6-16, Section 6.4.3, indicates that a template has been developed to better organize and access these various data sources, but no such example was available in the documentation. Finally, Harbour noted that Figure 11 is unclear how the median wage rate is used other than to provide an informal method to determine skewness and how this parameter impacts the Report findings.

Regarding the scaling methodology for other engine sizes, Assanis noted that the Report states that judicious scaling of the tear-down cost results is assumed to adequately represent other vehicles. While the scaling process is a critical part of the methodology, he said this is not adequately discussed. Other than the scaling assumptions documented in quote assumptions of the CBOM, a summary needs to be included.

Wade noted that the make-up of the cross-functional team that reviews all of the data from the high-level teardown is critical, but that the qualifications and experience of the cross-functional team members, which would be expected to affect the quality of the reviews, are not provided. He said this should be added because the qualifications and experience of the team could possibly affect the accuracy of overall costs.

Das, Harbour, and Wade all requested that additional information be added to the report regarding costing. Harbour noted that the Report should explicitly state the volume basis for the net incremental costs and whether the incremental costs are statistically significant at any volume or financially material (to the producer and/or to the consumer) at the proposed volume. Wade commented that to assess accuracy of cost estimates, an explanation of "total serial process time" input data should be provided, along with clarification of the phrase "referenced to mass production assumption calculations." Harbour requested that the Report provide the statistical basis for the library of costing models, such as the source of data, number of data points (samples), average, and standard deviation. Similarly, Das noted that the Report mentions that Munro & Associates costing software is used to calculate the primary fabrication parameters including part cost estimation, but insufficient documentation and references are provided on the estimation methodology. Also, he questioned whether this follows the same cost model principle outlined elsewhere in the report, including the manufacturing overhead database for investment cost information. Wade noted that the assignment of a low or high annual consumption rate affects pricing for a material, yet this is not reflected in Figure 7. He requested that the text of the Report state that the application of either low or high annual consumption rate pricing for a specific material be found in Appendix E and that confirmation of the pricing with supplier quotes be added and/or made apparent in the Appendix. He stated that this is viable since, at least for high annual consumption rate materials, pricing should have been confirmed with supplier quotes. Harbour stated that, for the most likely incremental cost drivers, presenting the assumptions used around differences to potential OEMs is critical. She said the Brief Explanation of Differences column needs to be classified by attribute and type of difference, such as weight and material.

Finally, regarding a specific calculation, Block Turbo Shaft Support – Cooling & Lub, Wade noted that the calculation includes four manual and four automatic stations to derive a parallel process multiplier of eight. Since this implies that all eight stations have labor associated with them, he requested that an explanation of why an “automatic” station needs to have a labor charge provided.

d. Comments on the Appendices

All reviewers provided comments on appendix materials. Many of the methodological or specific clarifications are addressed in other sections, as appropriate, but comments referring principally to editorial comments or omissions in the material are included here.

Assanis wondered how, due to size and format limitations, certain database files will be made available in hard copy form. Wade recommended that the appendices be re-labeled so that the designations E.1, F.1, etc. are clearly associated with the respective topic. Harbour, however, commented that the appendices are generally exceptional and indicate that information is derived from resources that know the industry.

More specifically, Das stated that the following omissions in the appendices should be addressed: Quote Assumptions, Component Specification Assumptions, Component Manufacturing Assumptions, and the Potential Component Suppliers in the CBOM for the included example. Also, he found the list of variables listed in Appendix F, Table F.1 (currently labeled Table E.1) to be inconsistent for the example case shown in Appendix G. Further, he noted that none of the outputs in Appendix G indicate the year (current vs. future) on which the cost analysis is based and that Appendix F.1 manufacturing process input parameters listed under “Project Process Requirements” disagree with those used in the actual example shown in Appendix G.

Appendix A - Charge to Peer Reviewers

Peer Reviewer Charge

<u>Charge to the Peer Reviewers of EPA's LD Technology Cost Report</u>

EPA's Light-Duty Technology Cost Analysis Report 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 light-duty highway vehicle GHG emissions standards. This report details the methodologies used by FEV and its subcontractor(s) to determine a cost for various light duty (LD) emission control strategies and reports the results of this work to date. No independent data analysis will be required for this review.

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, we ask that each subject matter expert 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.

In preparing their comments, each reviewer should 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. 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 the 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.

Appendix B - Dr. Dennis Assanis Response to Peer Review Charge

Review on Draft Report

“Light-Duty Technology Cost Analysis Pilot Study”

Prepared by FEV for EPA under contract No. EP-C-07-069 September 3, 2009

SUMMARY COMMENTS

The objective of this study is to determine incremental direct manufacturing costs for a set of advanced light-duty vehicle technologies which are on the leading edge for reducing emissions of greenhouse gases. To a large degree, the study is based on teardown of vehicle systems employing the new technologies, comparing differences with baseline, and costing the components and systems based on databases of materials, labor, manufacturing, overhead and mark-up costs to arrive at final results. The objective is pursued by laying out the general methodology and then applying it to assess the cost differences between a conventional I4 engine and a turbocharged downsized I4 engine.

In the spirit of improving the quality of the study and the report, the reviewer provides several general and detailed comments for consideration by the contracting agency and the authors of the report. The topic that EPA and FEV have attempted to tackle is both an important one and a hard one for arriving at a universal methodology for assessing cost differentials for implementation of new technologies into vehicles. Right from the outset, it should be recognized that the proposed methodology focuses more heavily on tracking component materials and manufacturing costs and less on system integration issues and costs. The latter are typically captured through experiential, proprietary indirect cost multipliers. To the extent that the new powertrain technologies are evolutionary versions of current technologies (for instance based on different materials and manufacturing processes for relevant components and sub-systems), the methodology has the potential to produce fairly accurate estimates of final costs. However, as components and systems become radically different than today’s versions, such as in electrified versus mechanical powertrains, both the manufacturing as well as the systems integration aspects of the methodology will be increasingly challenged.

Of the powertrain technologies identified for evaluation, some are advanced versions of current powertrains, i.e. downsized turbo-charged GDI, advanced diesel, advanced transmissions. Others such as HCCI and lean-burn GDI, while still predominantly mechanical powertrains, involve new challenges in electronics, calibration, and catalytic aftertreatment. In particular, the calibration of multi-variable, high degree of freedom systems can require more resources and time than their direct manufacturing costs. Beyond those, as electrification content in the vehicles is increasing, such as in hybrid electric vehicles, plug-in-hybrids and full electric vehicles, the availability of historical cost databases for relevant components (and especially batteries) is very limited. In addition, power electronics, system integration and power management strategies will become extremely important; the related R&D and calibration issues would not be captured well by currently used IC multipliers. In order to provide a general framework for assessing costs of different light-duty powertrain technologies, i.e. both currently deployed and emerging, more effort will need to go towards addressing the electrical side, ideally accompanied by a relevant case study.

Several critical assumptions of the methodology are not presented in the report, but instead reference is made to the Munro & Associates proprietary software Design

Profit®. While recognizing the need to protect proprietary intellectual property, the basic assumptions, math and algorithms should be described in the report to give the reader a basis for judgment without giving away sensitive cost figures, etc. This way more confidence can be built in the process followed, otherwise it has the appearance of a black box to the reviewers and readers.

The report cites the use of Indirect Cost multipliers to capture the full cost of a new powertrain technology, including OEM ED&T costs. While a detailed assessment of those factors is not within the state scope of the analysis, they constitute an important costs factor, especially for new technologies. The reviewer recognizes that EPA has recently published a study entitled "Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers". The present study should include a section presenting an executive summary of this companion study, along with a discussion of areas where improvement to that methodology needs to be made to deal with the R&D and calibration costs of some of the new technologies (especially high complexity, disruptive electrical technologies).

In numerous other cases in the report, instead of citing a published reference, recourse is made to a consultation between EPA and FEV, or feedback from a subject matter expert. In such cases, presentation of ranges and sensitivities considered, and a discussion of where the estimate selected for this study fell within the range would be more instructive to the reader.

COMMENTS ON ORGANIZATION OF REPORT

From an organizational perspective, the draft report relies considerably on presenting the proposed methodology in tandem with the illustrative case study. The inclusion of and reference to a large number of spreadsheets and databases in appendices makes it harder to clearly present the general methodology in the body of the report, outline the basis and assumptions, and critically assess what aspects of the methodology would need to be modified for assessment of mechanical, hybrid or electric powertrain architectures and various vehicle classes. The idea of including in the report a comprehensive case study is excellent. However, the report is lengthy at places, such as in presentation of specific examples, but too laconic at other places where key assumptions of the methodology are presented. The draft can definitely benefit from re-organization and better balancing of its chapters. A possible structure to consider follows:

- First, present the methodology so its assumptions and sensitivities become clear. Give special consideration to the fact that different powertrain platforms (beyond the one in the selected case study) need to be assessed.
- Following the presentation of the methodology, it would be helpful to summarize the required inputs for the analysis (e.g., description of required cost databases, material and manufacturing process cost information, labor rates, ICM rates, etc).
- The subsequent section should describe how the methodology and inputs are applied to a case study (which would be in the appendices). Following the presentation of results, essentially Table 1 of the present report, it would be useful to:

  (i) discuss the validation of the estimates against available industry-averaged data

(ii) present sensitivities of results to key assumptions, including select illustrations of what-if scenaria (e.g., different labor rates, volume discounts, ICM multipliers, etc). This exercise would be useful to highlight how different audiences of the report could use its content, in case they disagreed with key assumptions or had better cost (or other) data available.

- Budget permitting, a second case study pertaining to hybrid powertrains would be desirable, particularly because cost differential figures reported by industry are widely varying. In the absence of performing a second case study for a hybrid powertrain, a discussion of anticipated challenges to the methodology would be helpful.
- Finally, a summary, conclusions, and recommendations for further study need to be presented to close the report.

In general, there should be more discussion of the results presented in figures, tables, worksheets (e.g., assumptions made and input parameter ranges), and more critical assessment of results (e.g., which technologies, materials, processes seem to incrementally or additively contribute the most), rather than just summarizing the results in a table or figure. More discussion of uncertainties present in the analysis should be presented along with specific findings so as to enable the reader to place the findings into proper perspective. For instance, different OEMs pay different prices to suppliers for the same component. Currently, it is not apparent how a reader can extract useful output based on different set of critical assumptions and costs.

On another note, page numbering is confusing. I assume this will be corrected in the final report.

Also, due to size and format limitations, certain database files are not available in hard copy form. How will this impact the final report in hard copy form?

DETAILED TECHNICAL COMMENTS

Page 1-2: The new technologies characterized for study using the proposed approach are quantized into discrete bins, when in fact we could very well see in production hybrid versions of the options much sooner. For instance, some GDI engines could operate under the lean stratified mode when at part-load conditions, yet operate at homogenous stoichiometric conditions when requiring full power. The list in the report seems to suggest that GDI engines operate with “one or the other” strategy. Furthermore, GDI/HCCI employing spark-ignition for part of the range (start-up and high load) and HCCI combustion mode for all other regimes. In many ways, HCCI is a combustion mode that can be realized through the integration of several technology packages. While camless is one way to enable HCCI (and will require a longer time horizon), HCCI can be realized via the use of cam profile switching/ phasing and mechanical lift control. Depending on the implementation selected, the manufacturing, R&D and calibration costs can vary significantly.

Page 1-2: A notable omission from the list is flexible/alternative fuel powertrain packages.

Page 1-2: Discuss the basis for the assumption of an average volume of 450,000 units. How would results be sensitive if the volume were larger of smaller?

Page 1-3: Note typo in Flowchart. “Cross Fucntion” should be “Cross Function”.

Page A-0, 2nd and 3rd paragraphs: It is mentioned that reliable results can be obtained though *judicious scaling* of the tear-down results costs up or down across the relevant vehicle classes. While it is mentioned that the scaling process is a critical part of the methodology, it is not adequately discussed. Some scaling assumptions are documented in quote assumptions of CBOM. A summary needs to be inserted in this section.

Page A-0, section 3.1: The statement that no new technology was considered between a naturally-aspirated I4 and a downsized turbocharged engine is confusing.

Page 4.2 and 4.3: The description of the Design Profit methodology is too superficial and Figure 2 does not add much to the picture. The key assumptions and algorithms of the methodology need to be presented in this section, as it is central to the overall methodology. If Figure 2 is included, a discussion of the mapping process needs to accompany it.

Page 4.5, 3rd paragraph: “Most all of the processes” needs rewriting.

Page 4-5, 4th paragraph: “To accomplish this” needs to be followed by a comma.

Page 4-5, 4th paragraph: The factoring methodology used to deal with part variability needs more description.

Page 4-6, 1st paragraph: The worksheets used these input factors within formulas. This is too vague. Can a representative formula be given?

Section 5, page A-0: A section on IC multipliers, summarizing key findings of the companion EPA study, should be added to the present report (see also my earlier comment).

Page 5.2, first line: “…are involved..” Delete the extra period.

Section 6.3: The structure of labor wages and rates has changed significantly given the recent turmoil in the North American Automotive Industry (both OEMs and suppliers). However, certain estimates have been based on historical rates (e.g., on page 6-1, fringe rates have been based on a 2006/2007 average UAW OEM wage and labor rate).

Page 6-7, last line: An “Annual Adjustment Factors” should be corrected to “Annual Adjustment Factor”.

Appendix C - Mr. Sujit Das Response to Peer Review Charge

Review Comments

On

Light-Duty Technology Cost Analysis Pilot Study, FEV Draft Report, Sept. 3, 2009

By

Sujit Das, Oak Ridge National Laboratory, Oak Ridge, TN 37932-6205

(dass@ornl.gov; 865-946-1222)

October 5, 2009

1. Overall, the detailed cost estimation approach based on teardowns of vehicles than the past basis of supplier price quotes for key components appears to be a reasonable one. A lot of details have been addressed by using this bottom-up approach. This approach would work great for an existing technology, but finding a comparable vehicle where new technologies have been implemented may be difficult for the incremental cost estimation of new technologies. The approach seems to be prohibitively expensive and time-consuming for a regular use although scaling to what extent may avoid this problem is unclear. It'd be good to elaborate the scaling methodology for the report completeness.

2. The cost estimation approach becomes fuzzy after the Lean Design software converts serial processing operations into mass production operations. The methodology described here is not at all transparent, and at times ad-hoc procedure is used. The overall approach seems quite complex, requiring subjective judgments along the way. For example, in Sect. 4, it is mentioned that not all processes and operations are mapped in full detail using Design software, instead supporting information from other manufacturing cost estimating tools is used.

3. A lack of appropriate software documentation from the Munro & Associates website as well as some discussion in the FEV report makes it difficult to assess the validity of internal costing tools of Munro & Associates used to develop serial manufacturing process times including primary fabrication parameters and a consideration of part variability through a factoring methodology. It is not clear how manufacturing parameters have been linked to the parameters estimated by the suite of Munro & Associates software. A listing of various software used along with its scope would be useful. It would be good to know to what extent the validation of the Munro & Associates software has been done to date.

4. On pg. 4-4 last paragraph: Mentions that all primary fabrication processes, the parts are quoted using secondary cost estimating modules and the key process information is fed back into the process maps. Not clear what it means the linkage between primary fabrication processes and secondary cost estimating modules. Why secondary and not primary cost estimating modules?

5. Estimation of manufacturing overhead rates is one of the critical elements to the overall cost estimation process. It would be dependent on so many parameters and the database does neither indicate the estimation procedure and nor underlying assumptions. Pg. 6-16, Sect. 6.4.3, indicates that a template has been developed to better organize and access these various data sources – but no such example was available in the documentation.

6. It would be good to map five vehicle classes considered for the cost estimation to 13 EPA vehicle classes in accordance with 49 CFR part 523.

7. The average annual production volume assumption of 450K units for a robust market penetration rate may not be the same across various technology types if numerous suppliers would be involved in such a new technology component manufacturing at the same time. Since our cost estimation is based on an individual tier-level supplier, annual production volume needs to be appropriately adjusted based on the manufacturing technology and component type under consideration. Examples shown in Appendices did not indicate varying annual production assumptions.

8. The inclusion of MCR and NTAs assumptions in CBOM is an excellent option and they should rather be used more frequently to project future cost reductions with maturation of technologies. However, how these have been implemented into the overall cost estimation procedure is unclear.

9. Didn’t find the following sections in CBOM for the example included in the appendix of the document: Quote Assumptions, Component Specification Assumptions, Component Manufacturing Assumptions, and the Potential Component Suppliers.

10. On pg. 4-5 mentions that once the materials and primary processes used in making the part are identified, Munroe & Associates costing software is used to calculate the primary fabrication parameters including part cost estimation. Any documentation or reference available on the estimation methodology? Does this follow the same cost model principle as outlined in Sect. 5, including the manufacturing overhead database for investment cost information?

11. Is the Munroe & Associates costing software also used in the case of secondary processes as well? Mapping of these processes using Design Profit software is indicated on pg. 4-6, para 2, but not the costing procedure.

12. Under Sect. 1.1, para 2 mentions that the work assignment focus is on the determination of incremental direct manufacturing cost. It would be useful to define what does the direct manufacturing cost mean?

13. At the component level, T1 or OEM manufacturing cost is first calculated, and then T1 or OEM markup rate is used to estimate the T1 supplier cost. But for the final estimation of net cost impact to vehicle, IC multiplier is the only appropriate mark-up factor to be used which estimates vehicle level cost – it was not found to be applied in any of the cases. The concept of IC multiplier has been mentioned several times in the document, but the actual data used and its specific application was not found in the document. If cost level is limited to only at the T1 supplier level as appears to be the case for the example shown, how is tooling cost which has been assumed to be a part of

OEM cost, has been included in the analysis here? Also, different markup rates for T1 suppliers other than provided in Table 2, pg. 6-21 and mark up database spreadsheet file in some MAQS in Appendix G have been used. A further discussion regarding this in the document would be useful.

14. It is good to find that the some attention has been paid in the estimation of packaging cost. But the question is it worth the consideration since its contribution to the net incremental unit part cost may not be as significant compared to other cost categories.

15. It is unclear from para 2, p. 6-16, what method is used for the investment cost depreciation over the production volume in the estimation of manufacturing overhead rate.

16. Sect. 6.2.1, p. 6-2 mentions about annual consumption rates and source references in the materials database. But in Figures 7A and 7B they are not mentioned and also the material price based on what production volume to indicate where the volume sensitivity factor needs to be applied (the electronic database contained some of the information).

17. Quite a bit of subjective expert judgment is necessary for the material selection process for the unmarked materials (Sect. 6.2.2).

18. P. 6-10. Any basis why OEM fringe rate is more than three times higher than for tiered supplier manufacturing?

19. p. 6-22. It may not be accurate to apply the same level of mark-up regardless of the primary manufacturing process group and primary manufacturing equipment group involved. Besides the company size and part complexity, the actual manufacturing technology type would also influence the final mark-up rate.

20. End-Item Scrap Mark-up includes mainly the warranty cost if the cost methodology is based on the ANL Vyas et al. 2000 publication. It looks here this cost item also includes in-process scrap, which is more appropriate to be handled under manufacturing overhead rate reflecting better the technology characteristics.

21. Any source for the assumption of 0.3%-0.7% of the TMC for End-Item Scrap Mark-up? Derivation of this data from the cost review may be difficult for technologies yet to be commercialized.

22. Labor rate estimation approach is sound and based on a reliable public data source.

23. Pg. 9-3: the manufacturing assumption section, positioned to the right of the quote summary section in MAQS, is where the additional assumptions and calculations are made to convert the serial processing operations from Lean Design into mass production operations. Without explicit knowledge of these underlying assumptions and calculations, it is hard to verify the estimate accuracy.

24. Using a standard quoting template used by the automotive industry for the MAQS is an excellent approach -- specially for which this intense cost modeling effort deserves credit.

25. Sect. 9.3, pg. 9-5, para 2: Instead of Appendix E, Table E.1 should have been Appendix F, Table F.1. However, the detailed description provided in this appendix has been extremely useful. However, the list of variables listed here were not found to be consistent for the example case shown in Appendix G.

26. Why in Appendix G, the variable OEM/T1 Classification is not always shown on subsystem worksheets?

27. Appendix F.1 (pg. 4 of 16): Shouldn't the Material Usage "lb" variable be automatically uploaded from Process Mapping instead of a user input?

28. Appendix F. 1 (pg. 6 of 16): Tooling and Investment Assumptions are included but how are these incorporated into part cost estimation? Since tooling has been mentioned as a part of ICM of OEM and investment as manufacturing overhead, how are these different and estimated?

29. Appendix F. 1 (pg. 14 of 16): For the estimation of "Base Cost Impact to Vehicle", wouldn't the IC multiplier be used for at the final OEM level? Didn't find the use of it in the example presented.

30. Appendix F. 1 (pg. 10 of 16): Provides manufacturing process input parameters under "Project Process Requirements", but the variable names seem to be different than used in the actual example shown in Appendix G.

30. Consideration of maintenance and end-of-life costs has been given but the approach discussed hasn't been detailed enough and it appears to be a subjective one and not robust.

31. p. 12-2, para 2: mentions about "as discussed in Sect. 5.0, material costs include a combination of raw materials, material processing scrap, and commodity purchased parts." But material cost is discussed in Sect. 6 and material processing scrap has been included under "End-Item Scrap" based on the methodology described in the document.

32. Appendix G.1-03, 2 of 7: Although component has been manufactured by OEM, why isn't the ICM used in this case? Same in the case of Appendix G, 1-05, 2 of 8 and several others where OEM has been used as the supplier.

33. None of the outputs in Appendix G indicates the year (current vs. future) assumed on which the cost analysis is based.

Appendix D - Ms. Laurie Harbour Response to Peer Review Charge

Background

Harbour Results appreciates the opportunity to be a member of the review team to validate the methodology employed in the Light-duty Technology Cost Analysis Pilot Study, Contract No. EP-C-07-069, dated September 3, 2009. A team of four resources provided input to the feedback. These included Laurie Harbour, John Monica, and Rich MacInnes.

Our Charge as Reviewers

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.
- Subject matter expert comment on all aspects of the report, with particular emphasis
  - Costing methodology
  - Sources of information used in determining labor rates, material prices, manufacturing burdens and other key factors.

Each reviewer should distinguish -

- Between recommendations for clearly defined improvements that can be readily made, based on data or literature reasonably available to EPA
- 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.

Review Report Organization

To aid in the feedback, Harbour Results Inc. (HRI) has organized its feedback into the following four sections.

- General Feedback
- Feedback Classification
- Feedback order by report structure (HRI FEV 07-069-103F Review.xls)
- Feedback sorted by classification (HRI FEV 07-069-103F Review.xls)

General Feedback

HRI appreciates EPA's efforts to develop a detailed cost analysis "bottom-up" approach versus an economic "top down" approach to estimating impact of technology changes on the marketplace. We believe the most accurate forecasts and estimates must lever both perspectives. This report does not identify economic and marketplace assumptions.

HRI is concerned that the transportation industry is fragile and recovery will be a long time coming. However, without a clear and timely energy policy, consumers will not be motivated to drive small displacement engines. HRI recognizes that an energy policy that purposely increases in fuel prices will not play well in the marketplace. As such market forces that drive higher fuel prices combined with aggressive emission/greening regulations and value-based competitive offerings that meet these regulations, will likely shift consumer buying trends.

In North America typical engine penetration is mostly V6/V8 with 4 cylinder engines being less than 20%. This is largely due to consumer preferences and sustained by relatively low fuel prices ($2 – 3 per gallon) as compared to Europe, Asia and South America where prices are ($5-7 per gallon). Until consumer preferences and purchase motivation change achieving 4 cylinder volumes levels of 450K is unrealistically high. However, price pressures driving changes in manufacturing practices may offset current consumer buying practices.

It is critical to understand for this analysis the differences in vehicle volume versus engine volume. A typical vehicle volume today averages 80-90K units per year but the go forward strategy for all manufacturers is to commonize vehicle architectures around the globe which will enable sharing of major components across multiple vehicles and dramatically reduce cost per vehicle. The engine and the powertrain components are a major driver for this effort due to the cost impact. As a result powertrains will be designed and used in multiple models, for sale around the globe, where volumes up to 1 million or more engines can fit multiple models and segments. This volume may require multiple plants to produce for target markets.

HRI is also cognizant of the EPA's past efforts to forecast the impact of regulatory requirements the industry. HRI's industry contacts and research efforts indicate that EPA has consistently and significantly underestimated industry investment requirements. For example:

HRI's industry contacts and research suggest that the EPA has historically missed the mark in estimating and subsequently appropriately allocating R&D investments caused by new or significant changes in regulations. For example:

<u>EPA 2002 Regulation</u>	<u>Per Vehicle Cost</u>
EPA (Forecast)	$800 (lifetime impact)
Fleet Owners Assoc. (Actual)	$3,600 (First five years impact) 4.5 times EPA

<u>EPA 2007 Regulation</u>	<u>Per Vehicle Cost</u>
EPA (Forecast)	$900 Midsize
	$1,100 Class 8
OEM #1	$3,735 (4 times EPA)
OEM #2	$7,055 (6.4 times EPA)

EPA 2010 Regulation	Per Vehicle Cost	
EPA (Forecast)	$1,200 (Class 8)	
OEM #3	$5,561 (Class 6/7)	4.6 times EPA
OEM #2a	$7,470 (Class 8)	6.2 times EPA
OEM #2b	$5,619 (Class 8)	4.7 times EPA
OEM #4	$7,968 (Class 8)	6.6 times EPA
OEM #5	$6,640 (Class 8)	5.5 times EPA
OEM #5	$4,980 (Midsize)	4.4 times EPA

With the 2010 regulations the EPA averaged 1/6 of the cost of "industry stated" reality. Projecting the same performance on the study we are assessing we can conclude the following as a starting point:

EPA 2016 Light Vehicle	Per Vehicle Cost
EPA (Forecast)	approx. $571
Based on 2010 Forecast	$3,426 (6 times their estimate)

What is certain is the significant difference between EPA forecasts and industry's stated cost reality. HRI will not presuppose any motivation for these differences, but believes that the use of methodology contained in the FEV report will significantly narrow the gap between forecast and actual, in both tangible and intangible costs.

Feedback Classification

HRI has classified its report feedback into five groupings. These are described below:

- Technology – the use of information technology to develop and execute the cost modeling.
- Premise – the underlying assumptions used as the basis to derive cost model estimates.
- Methodology – process steps and sequence used to define and execute the cost model.
- Protocol – specific methods used to make decisions within the cost model.
- Operational Definition – clear articulation of the subject being defined such that it can be characterized and classified in a meaningful way.
- Statistical Validity – data used to support a premise, the argument, and subsequent conclusion is statistically valid. May require the use of statistical test, sensitivity, and/or uncertainty analysis.
- Presentation – how the report presents information to the intended reader.

Technology

Having already experienced Design Profit® technology in prior projects with Munro & Associates, HRI is confident in its valid integration of product design, manufacturing processes, and associated demand, cycle time, labor, material, costs, and forecast data. Further we are confident that the integration of information technology, such that changes made in one database/spreadsheet updates the linked fields in other applications.

Premise

Program Volumes - The study's model, utilizes a volume of 450K annual as a cost basis. Market reality is that the average vehicle model volumes are between 80 and 90 thousand annually. For every single 450K program utilized in the EPA study, there will actually be approximately 5 programs. Until common platforms are a reality or there is a dramatic change in consumer purchasing practices, the EPA should review its model to determine if it significantly understates the total amount of amortized fixed costs in supplier pricing.

While the Harbour Team does not dispute the method of calculation on an individual program, we do believe that the average numbers quoted from the EPA are approximately 1/5 the cost of what actual experience will be for this type of program. ED&T costs include application engineering costs that are packaged around a specific vehicle model. In essence, the EPA Model assumes that one Production Part Approval Process (PPAP) package will be submitted for five different vehicles.

Manufacturing Capabilities – The report needs to be explicit where current OEM and Supplier manufacturing equipment and facility capabilities are insufficient. Should demand for certain technologies exceed supply, OEMs will be forced to pay a premium for these parts to develop additional capacity. To assume sales below capacity for incremental costs modeling is specious.

Declining labor rates – It is unclear if the example used for the AAF of a 5% per year decline in supplier labor rates is for explanatory purposes or if it is the actual rate used to estimate productivity improvement at the supplier level. HRI disagrees with 5% decline in labor rates if this is the assumption used.

It's unclear what would support a declining labor rate assumption as inflation and generally increasing labor rates in the manufacturing sector is the norm. Declining labor rates is not the same economic concept as declining labor content due to process improvements. Further, we are concerned that Design Profit® assumes that the part will be manufactured in the leanest possible way in year 1, if so than a 5% reduction cannot be possibly obtained if they are already at optimal in the model.

Optimal manufacturing practices – HRI's experience is that manufacturing practices are less than optimal. As such we recommend a classification of processes that clearly distinguishes between batch and lean. Further review may necessitate a sensitivity analysis showing a mix of practices that are more "batch" oriented.

Mature technology impact on R&D investments – Industry may push pack on general assumption that the product technology is mature, or something they would have already planned to invest in. This will be especially true if EPA regulations mandate significant emission reductions, over current planned R&D efforts. Harbour Results recommends that the EPA pole industry participants to validate technology maturity and estimate the amount of R&D that will be built into piece price of suppliers. R&D assumptions from this report should not be extrapolated to all new technology designed to reduce emission, e.g. lithium battery technologies.

It is our understanding that the world-wide investment in R&D by the automotive OEMs is $16-17 billion; this estimate does not include supplier R&D investments. Further that R&D investment can be broken out in four distinct categories of new product development, fuel economy improvement and emissions, pure research, and plant energy and emissions. See Figure 1 below. It may benefit the study if EPA classified proposed technology changes into one or more of these categories. Then develop a total cost versus incremental cost model. This will enable EPA to frame the total impact and then argue whether it is incremental in sum or in parts.

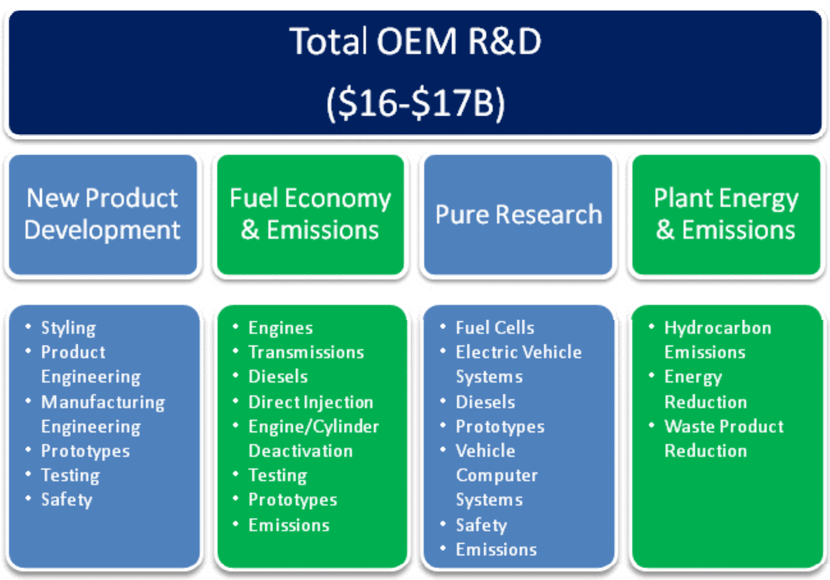

Figure 1 - OEM 2007 R&D Investment Categories

<u>Smoothing of price spikes through regression analysis</u> – Uncertainty analysis should validate other proxies of prices, such as raw material (product content) cost trends, exchange rate fluctuations, and so on, then subsequently indexing these to the price models used.

Methodology

The overwhelming majority of methodologies employed in this study appear to be sound. Improvements include the following.

Emissions Impact - HRI recommends that EPA classify various parts identified in the CBOMs by their "known" or "projected" impact on emissions, so costs (industrial and consumer investments) can be more expertly attributed to performance capabilities that matter. This is the basis for most value engineering studies, e.g. link design criteria to desired performance criteria that matters such that necessary investments can be aligned.

Torque Variables - Develop list of torque variables ranked by their financial impact and their impact on lowering emission. Torque variables can singularly influence the financial materiality or discernable improvements in emission levels. Examples of torque variables include proprietary material composition, engineered items, union labor content, OEM/T1/T2/T3 responsibility, and so on.

Align uncertainty factors (refer to statistical validity comments) to torque variables while ultimately aligning and ranking both to their impact on lowering emissions.

Design Profit® Scoring – It is unclear if Design Profit® Scoring - e.g. Munro Scoring, Eng Hrs., No Gets… impact cost estimates. Is this used as a baseline of practices much like DFMA? If so what is a typical score and do you account for the differences in an "ideal" process and "standard/mainstream" scores in determining cost impact? Simply put, is Design Profit® costing on an ideal design and manufacturing flow which may appear to make cost look lower?

Proprietary Materials - Sound logic is used for unknown proprietary material compositions. Use of marketing firms to trend future prices as compared similar material trends is also sound. Consideration should be given to why proprietary materials are typically used to offset other lifecycle costs, e.g. extended product life, improved performance, less warranty costs, lower cost of ownership. To the contrary, proprietary materials typically increase start-up and validation costs. HRI assumes these factors are addressed in Indirect Costs.

Protocol

Technology Selection - What is the protocol employed to determine if differences in emission benefits and cost factors, base v. new are worthy of industry investment and consumer investment?

Design Difference - Need protocol definition for how parts were deemed to be excluded from cost analysis.

Operational Definition

MCR and NTA - Excellent distinction between MCR and NTAs; need better operational definition that attempts to void all future arguments regarding the use of this classification.

Standard/Mainstream Practices - Need operational definition of standard/mainstream industrial practices.

Part Hierarchy - Report uses mixed and confusing definition of system/subsystem/high level modules/modules/top level components/assemblies/components/end-item components/piece parts/parts hierarchies. Often uses multiple terms to describe the same part. Hierarchy needs to be defined and consistently used throughout analysis.

Volume Levels - Need operational definition of high and low volumes, not just an example; albeit the Viton® flouroelastomer is an exceptional example.

Quote Types - "Component level quotes" appear to be logically classified as full quote, modification quote, and differential quote. However operation definitions need to be developed with clear examples to avoid industry pushback.

Impact - Need operational definition of high impact purchased parts, low impact purchased parts and commodity parts.

Statistical Validity

Expert Statistical Review - A statistical expert review needs to be added as a final step to validate that the resultant costs are indeed statistically different for both materials, labor and combined into direct manufacturing costs. Data used for comparison needs to described by a mean and a standard deviation to be sufficient. It is unclear if proposed average costs of the new engine are easily within the price variations assumptions of the baseline engine... suggesting no differences. Pennies matter or do they? Nor are there any stated assumptions that the future prices will have equal variation between the baseline and new engines. HRI fears that some cost assumptions are based on one data point (our opinion) and aren't statistically sufficient.

Regression Analysis - Unclear if regression analysis is of price averages, Figure 9. If so a statistical test of homoscedasticity (homogeneneity of variances) is required.

Uncertainty Analysis - Develop list of uncertainty factors such as how many engines will be replaced by emerging technology exemplified in study, lack of significant industry information (price, materials, production methods, and so on), significant volatility in prices behavior, questionable supply surety, newness of technology, labor ratios (union to non-union mix), country of origin, and so on. Uncertainty analysis should validate other proxies of prices, such as raw material (product content) cost trends, exchange rate fluctuations, and so on, then subsequently indexing these to the price models used.

Sensitivity Analysis - How does analysis forecast the labor mix (union/non-union) for a future date? Has a sensitivity analysis been conducted for variation in this mix as union wages and benefits appear to be significant cost factors, e.g. 160% Fringe for Union (pg 6-10).

Use of Median - In Figure 11 it is unclear how the median wage rate is used other than an informal method to determine skewness. How does it impact the report findings?

Arbitrary Factors - Active rates and mark-ups appear arbitrary and not derived. When arbitrary numbers are used it increases the need to do sensitivity analysis.

Presentation

Data Architecture Diagram - A data architecture diagram indicating which secondary cost estimating modules, Munro cost databases, et al (library of costing models - p 4-6) are used and how they feed into Design Profit® would be useful for the EPA to put forth their premises, arguments, and conclusions (logic construct) for future regulations. All data sources should be validated statistically (classified as either parametric or non-parametric) with hypothesis stated regarding differences between base and new technology.

Information Flow Diagram - A more detailed diagram showing flow of information into and out of the MAQS worksheet would be useful in presenting the validity of the data and methods used. This is especially true as you link the logic of complexity to mark-up levels as shown in Figure 14.

Feedback order by report structure

All feedback has been placed in a spreadsheet by the occurrence of the presenting issue in the draft report. Refer to HRI FEV 07-069-103F Review.xls

FEV Draft Report Review		FEV 07-069-103F
Page #	Comment Classificati	Comment
i	N/A	None
ii	N/A	None
iii	N/A	None
iv	N/A	None
v	N/A	None
ES-1	Premise	What is the bigger question EPQ is trying to answer with this study? Is it just to replace the 2.4L engine with a more environmentally friendly 1.6L engine? Or does the EPA plan on extrapolating results for comparison to other engine technologies currently deployed or planned for the future. This significantly impacts the level of assumptions and data required to answer these bigger questions.
ES-2	Premise	Table needs to state explicitly the volume basis for the net incremental costs and whether the incremental costs are statistical significant at any volume or financially material (to the producer, to the consumer) at the propose volume
p1-1	N/A	None
p1-2	Premise	The study's model, utilizes a volume of 450K annual as a cost basis. Market reality is that the average vehicle model volumes are between 80 and 90 thousand annually. For every single 450K program utilized in the EPA study, there will actually be approximately 5 programs. Based on this reality, the EPA should review its model to determine if it significantly understates the total amount of amortized fixed costs in supplier pricing. While the Harbour Team does not dispute the method of calculation on an individual program, we do believe that the average numbers quoted from the EPA are approximately 1/5 of what actual experience will be. ED&T costs include application engineering costs that are packaged around a specific vehicle model. In essence, the EPA Model
p1-3	Technology	Phase 1 box cite Design Profit® technology, whereas pg 1-5 cites Lean Design® technology. Unclear if there is a relationship between the two technologies.

Figure 2 – Sample of Feedback by Report Page Number

Feedback sorted by classification

All feedback has been placed in a spreadsheet by classification of the presenting issue in the draft report. Refer to HRI FEV 07-069-103F Review.xls

FEV Draft Report Review		FEV 07-069-103F
Page #	Comment Classificati	Comment
p1-3	Technology	Phase 1 box cite Design Profit® technology, whereas pg 1-5 cites Lean Design® technology. Unclear if there is a relationship between the two technologies.
p1-5	Technology	Reference to Lean Design® technology. Is this part of the Design Profit® package?
p1-6	Technology	Reference to Lean Design® technology. Is this part of the Design Profit® package?
p4-1	Technology	Flow on p1-3 states Lean Design® is used. Section 4.2 states Design Profit® used. Is the Munro & Associates internal costing tool - Lean
p6-1	Technology	Cost database integration and automatic updates to "active Rates" is exceptional. HRI assumes that these linkages have been tested for completeness.
p9-5	Technology	Lean Design® technology discussed. Is this a module of Design
ES-1	Premise	What is the bigger question EPQ is trying to answer with this study? Is it just to replace the 2.4L engine with a more environmentally friendly 1.6L engine? Or does the EPA plan on extrapolating results for comparison to other engine technologies currently deployed or planned for the future. This significantly impacts the level of assumptions and data required to answer these bigger questions.
ES-2	Premise	Table needs to state explicitly the volume basis for the net incremental costs and whether the incremental costs are statistical significant at any volume or financially material (to the producer, to the consumer) at the propose volume
p1-2	Premise	The study's model, utilizes a volume of 450K annual as a cost basis. Market reality is that the average vehicle model volumes are between 80 and 90 thousand annually. For every single 450K program utilized in the EPA study, there will actually be approximately 5 programs. Based on this reality, the EPA should review its model to determine if it significantly understates the total amount of amortized fixed costs in supplier pricing. While the Harbour Team does not dispute the method of calculation on an individual program, we do believe that the average numbers quoted from the EPA are approximately 1/5 of what actual experience will be. ED&T costs include application engineering costs that are packaged around a specific vehicle model. In essence, the EPA Model

Figure 3 - Sample of Feedback Sorted by Classification

Summary Remarks

HRI again thanks the EPA for the opportunity to participate in the review of the Light-duty Technology Cost Analysis Pilot Study, Contract No. EP-C-07-069, dated September 3, 2009. It believes that methodology of this cost study is directionally correct and should assist the EPA is bridging what industry considers consistent misestimates of market impact of its regulations.

Although the methodology is directionally correct, HRI believes that the EPA needs to revisit its premises, operational definitions, and statistical validation methods to ensure completeness and usefulness of the cost model. Premises like engine volume assumptions, perfect production methods, allocation and estimates of R&D investments and so on need further review. The EPA needs to clearly state operational definitions for how it defines volumes, impact levels, quote types, and so on, versus how the industry might define them. The EPA should test the statistical validity and financial materiality of all derived data. It should extend the sensitivity analysis to arbitrary (weighting) factors used in this analysis. Lastly the EPA would be well served by an uncertainty analysis of its input data and assumptions.

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
i	N/A	None
ii	N/A	None
iii	N/A	None
iv	N/A	None
v	N/A	None
ES-1	Premise	What is the bigger question EPA is trying to answer with this study? Is it just to replace the 2.4L engine with a more environmentally friendly 1.6L engine? Or does the EPA plan on extrapolating results for comparison to other engine technologies currently deployed or planned for the future. This significantly impacts the level of assumptions and data required to answer these bigger questions.
ES-2	Premise	Table needs to state explicitly the volume basis for the net incremental costs and whether the incremental costs are statistical significant at any volume or financially material (to the producer, to the consumer) at the propose volume
p1-1	N/A	None
p1-2	Premise	The study's model, utilizes a volume of 450K annual as a cost basis. Market reality is that the average vehicle model volumes are between 80 and 90 thousand annually. For every single 450K program utilized in the EPA study, there will actually be approximately 5 programs. Based on this reality, the EPA should review its model to determine if it significantly understates the total amount of amortized fixed costs in supplier pricing. While the Harbour Team does not dispute the method of calculation on an individual program, we do believe that the average numbers quoted from the EPA are approximately 1/5 of what actual experience will be. ED&T costs include application engineering costs that are packaged around a specific vehicle model. In essence, the EPA Model assumes that one PPAP package will be submitted for five different vehicles.
p1-3	Technology	Phase 1 box cite Design Profit® technology, whereas pg 1-5 cites Lean Design® technology. Unclear if there is a relationship between the two technologies.
p1-3	Methodology	Process Methodology "flow" is logical
p1-3	Statistical Validity	A statistical expert review needs to be added as a final step to validate that the resultant costs are indeed statistically different for both materials, labor and combined into direct manufacturing costs. Data used for comparison needs to described by a mean and a standard deviation to be sufficient. It is unclear if proposed average costs of the new engine are easily within the price variations assumptions of the baseline engine... suggesting no differences. Pennies matter or do they? Nor are there any stated assumptions that the future prices will have equal variation between the baseline and new engines. HRI fears that some cost assumptions are based on one data point (our opinion) and aren't statistically sufficient.

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p1-4	Premise	Unclear if vehicle classification is useful in determining the potential application of the 1.6L engine (and their competitive alternatives - Honda already produces 1.3 and 1.5L engines) and thus the "forecasted" industry production volume
p1-5	Operational Definition	Excellent distinction between MCR and NTAs. Just need better operational definition that attempts to void all future arguments regarding the use of this classification
p1-5	Technology	Reference to Lean Design® technology. Is this part of the Design Profit® package?
p1-6	Technology	Reference to Lean Design® technology. Is this part of the Design Profit® package?
p1-7	Statistical Validity	Step 8: What is EPA's definition of financial materiality? E.g. % of market price, defined difference between baseline and new. Again is the financial materiality statistically different?
p1-7	Methodology	Para 1.3 - HRI would argue that use of off-shore suppliers may not by default reduce costs due to increases in freight costs, tariffs, and unmeasured internal supply/program management resources. Furthermore exchange rate changes will impact sourcing as inflation rises.
p1-8	Premise	HRI associate challenges 450,000 unit volume basis
p1-8	Premise	Report needs to be explicit in where current OEM and Supplier manufacturing equipment and facility capabilities are insufficient.
p1-8	Operational Definition	Need operational definition of standard/mainstream industrial practices
p2-1	Methodology	Be prepared to discuss the "judicious scaling" protocol used to industry leaders
p3-1	Methodology	HRI recommends that EPA classify various parts identified in the CBOMs by their "known" or "projected" impact on emissions, so costs (industrial and consumer investments) can be more expertly attributed to performance capabilities that matter. This is the basis for most value engineering studies, e.g. link design criteria to desired performance criteria that matters such that necessary investments can be aligned.
p3-1	Protocol	What is the protocol employed to determine if differences in emission benefits and cost factors, base v. new are worthy of industry investment and consumer investment?
p3-2	Operational Definition	Report uses mixed and confusing definition of system/subsystem/high level modules/modules/top level components/assemblies/components/end-item components/piece parts/parts hierarchies. Often uses multiple terms to describe the same part. Hierarchy needs to be defined and consistently used throughout analysis.
p3-2	Protocol	Need protocol definition for how parts were deemed to be excluded.
p3-2	Methodology	Consider classifying parts as repairable or replaceable as this affects the consumer's cost of ownership
p3-2	Methodology	Need to state who or what validates the "fitness for use" of NTAs.

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p3-2	Methodology	Does EPA make a distinction in manufacturing practice breakthroughs versus product design breakthroughs in its NTA classification?
p3-3	Operational Definition	Modules, top level components, end-item components, parts, are introduced as new terms in the system hierarchy. It is okay to use the same term in the same sentence when describing a hierarchy. "Item" may be the best generic term to use universally as this is typically associated to an inventory item master.
p4-1	Operational Definition	Term high level modules introduced as part of the Design Profit® nomenclature.
p4-1	Technology	Flow on p1-3 states Lean Design® is used. Section 4.2 states Design Profit® used. Is the Munro & Associates internal costing tool - Lean Design®?
p4-2	N/A	None
p4-3	Methodology	The Design Profit® technology uses a sound approach to depicting work flows and resource utilization. It appears to be a static treatment of data (point in time), whereas other simulation software dynamically modules manufacturing behavior and may provide a better understanding of cost variances over time.
p4-4	Methodology	Unclear if Design Profit® Scoring - e.g. Munro Scoring, Eng Hrs., No Gets… impact cost estimates. Is this used as a baseline of practices much like DFMA? If so what is a typical score and do you account for the differences in a "ideal" process and "standard/mainstream" scores in determining cost impact? Simply put, is Design Profit® costing on an ideal designs and manufacturing flow which may appear to make cost look lower?
p4-5	Presentation	A data architecture diagram indicating which secondary cost estimating modules, Munro cost databases, et al (library of costing models - p4-6)are used and how they feed into Design Profit® would be useful for the EPA to put forth their premises, arguments, and conclusions (logic construct) for future regulations. All data sources should be validated statistically (classified as either parametric or non-parametric) with hypothesis stated regarding differences between base and new technology.
p4-5	Methodology	Material identification methodology is sound. Use of tell tale signs demonstrates real industry knowledge; this is exceptional.
p4-5	Methodology	Manual input "cost" parameters are sound. Accounting for part variability is exceptional.
p4-6	Statistical Validity	Provide statistical basis for library of costing models, e.g. source of data, number of data points (samples), average, and standard deviation.
p4-7	Methodology	Process mapping sound.
p5-1	Methodology	HRI sees no major flaws in the IC multiplier logic.
	Premise	Reviewed the Automobile Industry Retail Price Equivalent and Indirect Cost Multipliers report. Many of the premises set forth in this report apply to this study and should be incorporated.
p5-1	Methodology	Sound logic used for application of shipping costs
p5-2	Methodology	Sound logic used for tooling cost allocation

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p5-2	Methodology	Sound logic used for Investment cost as part of manufacturing overhead. Unclear how or if unique investment costs are factor in or just referenced?
p5-2	Methodology	Sound logic used for Product Development costs
p6-1	Technology	Cost database integration and automatic updates to "active Rates" is exceptional. HRI assumes that these linkages have been tested for completeness.
P6-1	Premise	It is unclear if the example used for the AAF of a 5% per year decline in supplier labor rates is for explanatory purposes or is the actual rate used to estimate productivity improvement at the supplier level. HRI disagrees with 5% decline in labor rates if this is the assumption used. It's unclear what would support a declining labor rate assumption as inflation and generally increasing labor rates in the manufacturing sector is the norm. Declining labor rates is not the same economic concept as declining labor content due to process improvements. Further, we are concerned that Design Profit® assumes that the part will be manufactured in the leanest possible way in year 1, if so than a 5% reduction cannot be possibly obtained if they are already at optimal in the model.
p6-2	Methodology	Agree with use of Annual Adjustment Factor (AAF).
p6-3	Statistical Validity	Unclear if there are known variances in the active rate and if/how these are accounted for in determining either statistical differences and/or financial materiality
p6-4	Methodology	Statement made "annual consumption rate which impacts whether high or low volume prices are used" Is HRI correct to assume that a nominal or mean rate is also used, not just high or low?
p6-4	Operational Definition	Need operational definition of high and low volumes, not just an example; albeit the Viton® flouroelastomer is an exceptional example.
p6-4	Methodology	Sound logic applied to material identification. However consideration should be given to whether a mistaken material selection would be financially material. This may stave off potential future objections.
p6-5	Methodology	Sound logic to developing pricing when not known: industry consultation and composition analysis. However, unclear how forecasting of future prices are extrapolated from limited input.
p6-6	Methodology	Sound logic used for unknown proprietary material compositions. Use of marketing firms to trend future prices as compared similar material trends is also sound. Consideration should be given to why proprietary materials are typically used to offset other lifecycle costs, e.g. extended product life, improved performance, less warranty costs, lower cost of ownership. To the contrary, proprietary materials typically increase start-up and validation costs. HRI assumes these factors are addressed in Indirect Costs.

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p6-6	Statistical Validity	In addition to the sensitivity analysis, the EPA should perform an uncertainty analysis for ill-defined or unknown materials, manufacturing and procurement practices that materially affect cost outcomes. Per EPA definition, uncertainty analysis investigates the effects of lack of knowledge or potential errors of model inputs (e.g., the "uncertainty" associated with parameter values) and when conducted in combination with sensitivity analysis (see definition) allows a model user to be more informed about the confidence that can be placed in model results. Source: Models Guidance Draft - November 2003 - Draft Guidance on the Development, Evaluation, and Application of Regulatory Environmental Models. Uncertainty analysis should validate other proxies of prices, such as raw material (product content) cost trends, exchange rate fluctuations, and so on, then subsequently indexing these to the price models used.
p6-7	Statistical Validity	Unclear if regression analysis is of price averages. If so a statistical test of homoscedasticity (homogeneneity of variances) is required.
p6-7	Statistical Validity	Uncertainty analysis should validate other proxies of prices, such as raw material (product content) cost trends, exchange rate fluctuations, and so on, then subsequently indexing these to the price models used.
p6-8	N/A	None
p6-9	Statistical Validity	How does analysis forecast the labor mix (union/non-union) for a future date? Has a sensitivity analysis been conducted for variation in this mix as union wages and benefits appear to be significant cost factors, e.g. 160% Fringe for Union (pg 6-10).
p6-9	Methodology	Sound logic for calculating and applying indirect labor ratio.
p6-9	Methodology	Sound logic for calculating labor rate.
p6-11	N/A	None
p6-12	Statistical Validity	Figure 11. Unclear how the median wage rate is used other than an informal method to determine skewness. How does it impact the report findings? Not sure the value of using the mode, other than to show the dominate recurring wage rate.
p6-13	N/A	None
p6-14	Statistical Validity	Figure 12. Active rates appear arbitrary and not derived. When arbitrary numbers are used it increases the need to do sensitivity analysis.
p6-15	N/A	None
p6-16	Methodology	Agree with machine based burden rates
p6-16	Methodology	Agree with activity-based burden rates
p6-16	Methodology	Acquiring Manufacturing Overhead Data is the most nebulous part of this report. More explanation of sources needed to support numbers.
p6-17	N/A	None

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p6-18	Statistical Validity	Figure 13. Rates appear arbitrary and not derived. When arbitrary numbers are used it increases the need to do sensitivity analysis.
p6-19	Methodology	Sound logic used for end-item scrap mark-up.
p6-19	Statistical Validity	Scrap mark-ups appear arbitrary. When arbitrary numbers are used it increases the need to do sensitivity analysis.
p6-20	Methodology	Sound logic used for SG&A mark-up.
p6-20	Statistical Validity	SG&A mark-ups appear arbitrary. When arbitrary numbers are used it increases the need to do sensitivity analysis.
p6-20	Methodology	Sound logic used for profit mark-up. What is unclear is where proprietary or unknown materials are used and the value of the impacted component in achieving more desirable emission levels. This might suggest a higher profit margin being sought on critical components.
p6-20	Methodology	Sound logic for ED&T mark-up.
p6-20	Statistical Validity	ED&T mark-ups appear arbitrary. When arbitrary numbers are used it increases the need to do sensitivity analysis.
p6-20	Premise	Industry may push pack on general assumption that the product technology is mature, or something they would have already planned to invest in. This will be especially true if EPA regulations mandate significant emission reductions, over current planned R&D efforts. Harbour Results recommends that the EPA pole industry participants to validate technology maturity and estimate the amount of R&D that will be built into piece price of suppliers. R&D assumptions from this report should not be extrapolated to all new technology designed to reduce emission, e.g. lithium battery technologies.
p6-21	Methodology	Sound logic used for Primary Equipment Groupings in Table 2.
p6-22	Methodology	Sound logic used for Tier 2/3 supplier mark-ups
p6-23	Statistical Validity	Sensitivity analysis required for different classification discussed in Table 3.
p6-24	Methodology	Sound logic used for packaging selection and costs.
p7-1	Methodology	Sound logic used for Shipping Costs
p8-1	Methodology	Sound logic used for commodity-based purchased parts
p9-1	N/A	None
p9-2	Presentation	A more detailed diagram showing flow of information into and out of the MAQS worksheet would be useful in presenting the validity of the data and methods used. This is especially true as you link the logic of complexity to mark-up levels as shown in Figure 14.
p9-2	Operational Definition	"Component level quotes" appear to be logically classified as full quote, modification quote, and differential quote. However operation definitions need to be developed with clear examples to avoid industry pushback.

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
p9-3	Premise	Recommend that study classify manufacturing operations as lean or mass in MAQS, and be prepared to sort accordingly as these approaches may have significant cost differences. HRI suspects that most of the differences in current manufacturing practices will be in the application of lean practices. Meaning the industry may experience higher "batch" processing costs than estimated by the model.
p9-4	Operational Definition	Need operational definition of high impact purchased parts, low impact purchased parts and commodity parts.
p9-5	Technology	Lean Design® technology discussed. Is this a module of Design Profit®?
p10-1	Statistical Validity	Differential analysis logic appears sound. Still question statistical basis for assuming differences in means between base and new.
p10-2	N/A	None
p11-1	Premise	How can an engine with new or proprietary materials as well as physical designs have no change in maintenance or end of life costs?
p12-1	N/A	None
p12-2	Statistical Validity	The sensitivity study should also include changes in arbitrary weighting factors.
A.1	Premise	Was the Vehicle Class Summary used to identify target vehicle platforms that would likely adopt the new engine technology? Was this profile used to set expected volumes?
B.1	N/A	None
C.1	Operational Definition	Naming convention - Subsystem, sub-subsystem, assembly, subassembly, component is well stated. The report does not read this consistent. Do levels change as data is entered in Design Profit®
C.1	Methodology	Brief Explanation of Differences column needs to be classified by attribute and type of difference, e.g. weight, material, and so on. Given the vast amount of information contained in these worksheets, presenting the assumptions around differences to potential OEMs will be critical as these are most likely the incremental cost drivers.
D.1	Operational Definition	It would be value adding to have a consistent hierarchy and part naming between spreadsheets, Design Profit® and the report.
E.1-E.5	Methodology	Unclear why 2015 and 2020 chosen as forecast points in time. Does EPA assume that the technology will still be leading edge by then? Or there is statistical significance to these years?
F.1	Statistical Validity	Classify any worksheet section that requires statistical validation, e.g. data quantity, average, std dev., sensitivity analysis, uncertainty analysis
F.1	Methodology	This appendix is exceptional. This section alone validates that the assumptions come from resources who know the industry.
G.1	N/A	None
H.1	N/A	None
H.2	N/A	None

Harbour Results, Inc. Summary FEV		
Draft Report Review		FEV 07-069-103F
Page #	**Comment Classification**	**Comment**
General	Premise	Does the EPA take into consideration other design features such as aerodynamics, rolling resistance, type of fuel, weight and so on that work in combination with the engine technology to achieve emission levels. Does it intend to bundle all these factors to determine the overall industry and consumer costs to achieve certain emissions levels as part of its regulatory efforts? We believe industry may challenge the individual system analysis and its impact on emissions.
General	Methodology	Develop list of torque variables ranked by their financial impact and their impact on lowering emission. Torque variables can singularly influence the financial materiality or discernable improvements in emission levels. Examples of torque variables include proprietary material composition, engineered items, union labor content, OEM/T1/T2/T3 responsibility, and so on.
General	Statistical Validity	Develop list of uncertainty factors such as how many engines will be replaced by emerging technology exemplified in study, lack of significant industry information (price, materials, production methods, and so on), significant volatility in prices behavior, questionable supply surety, newness of technology, labor ratios (union to non-union mix), country of origin, and so on.
General	Methodology	Align uncertainty factors to torque variables while ultimately aligning and ranking both to their impact on lowering emissions
General	Premise	This study gets in the weeds so fast that HRI feels that the EPA may lose sight of the bigger issues and challenges facing such a technology shift. HRI however does appreciate the use of such methodologies to improve the accuracy and reliability of its economic impact studies. Our clients have been historically at odds with EPA forecasted impacts and costs. This is a step in the right direction in closing those gaps.

Appendix E - Mr. Wallace Wade Response to Peer Review Charge

U.S. Environmental Protection Agency (EPA) Peer Review

of Draft Report, FEV 07-069-102F Dated September 3, 2009
"Light-Duty Technology Cost Analysis Pilot Study"

Peer Review by Wallace. R. Wade
October 5, 2009

Overview of the Draft Report

The "Light-Duty Technology Cost Analysis Pilot Study" describes FEV's methodology for determining incremental, direct manufacturing costs for a set of advanced light-duty vehicle technologies for the control of GHG emissions and the application of the methodology to a pilot program. The methodology consists of the following approach:

- New technology systems for the control of GHG emissions and comparator baseline systems are identified.

  The pilot study evaluated stoichiometric GDI with turbocharging on a downsized I4 engine (new technology) compared to an equivalent (hp and torque) conventional PFI normally aspirated (NA) I4 engine (comparator baseline). The following specific production engines were selected for the pilot study:

  New Technology: 1.6L I4 16V Double Overhead Cam (DOHC) Turbo Direct Injection (DI) with Variable Valve Timing (VVT) Peugeot Soceite Anonyme (PSA) Peugeot-Citroen engine in BMW Mini Cooper S, Hard Top vehicles)

  Comparator Baseline: 2.4L I4 16V DOHC NA with VVT (Chrysler, Hyundai, Mitsubishi engine in Chrysler Sebring, Dodge Avenger, Caliber, Journey, Jeep Compass, Patriot vehicles)

- Cost analysis of the production hardware systems was performed as follows:

  - Tear down of the production hardware systems
  - Evaluation on a part-by-part basis of observed differences in size, weight, materials, machining steps and other parameters affecting cost.
  - Use of databases for material costs, labor rates, manufacturing overhead rates, mark-up rates and packaging costs to calculate costs to fabricate individual parts and subsystems which are added together to provide the overall system costs.

The pilot study concluded that the net incremental/assembly cost impact to the OEM was $537.70.

<u>Overall Opinion</u>

(Note: All page references are to PDF document page numbers.)

FEV has developed and applied a detailed, objective methodology for determining net incremental/assembly cost impact to the OEM for new technology powertrains with reduced

GHG potential. In addition to providing EPA with the capability to estimate the cost of technology to meet regulations, this methodology is expected to be useful as EPA invites OEM's and suppliers to review, compare and rationalize their costs with those developed by EPA using this methodology (Ref: conference call 9/21/09). Although FEV's methodology ideally should yield accurate results, this peer review of FEV's report indicates that there are potential issues with the methodology that may affect the accuracy of the results. These potential issues are summarized below and are discussed more extensively in the Discussion section (using the same numbering scheme for the major topics and opinions).

A. Specific Opinions and Recommendations:

Opinion #1 – This methodology is designed to determine incremental, direct manufacturing costs for new technology vs. comparator baseline technology. However, incremental, direct manufacturing costs are only part of the price to society for new technology.

Recommendation #1 - Manufacturers also incur indirect costs. The recently derived Indirect Cost Multipliers developed by EPA to account for vehicle modifications associated with environmental regulations should be applied to these direct costs to determine the price of the new technology to society.

Opinion #2 - The methodology makes extensive use of proprietary software and databases, which are not available for peer review. Without detailed information regarding these proprietary tools, the accuracy of the cost estimates cannot be determined. The following proprietary tools are used in the methodology:

1. Lean Design software developed by Munro & Associates is used for mapping high-level processes and calculating complete process times (Page 13 (Step 4) and Page 105 (Appendix F.1)).
2. Design Profit software is utilized to map high-level modules within each system/subsystem (Page 21) and all secondary processes (page 26) and contains maps and costing databases used as input to the MAQS (Page 14, Page 21, Page 26, and Page 27 (Figure 4)).
3. "An applicable database" is used to provide "surrogate costs" when a part is treated as a "buy" (Page 19).
4. "Purchase Part Database" is used to provide values for commodity purchased parts (Page 207, Appendix G.1-60 (4of4), Engine Electrical Systems – Engine Assembly MAQS spreadsheet).

The Report is not clear about how the above four software and databases are related to each other.

5. Databases for material costs, labor rates, manufacturing overhead rates, mark-up rates, and packaging costs provide the foundation of the cost analysis (Page 30 and page 95, Appendix E.1-E.5). (These Appendices were provided separately on September 29,2009, which limited the review time prior to the peer review submission date of October 5, 2009.)

In addition, descriptions of how the proprietary software and databases were validated (i.e., demonstration of similar outputs of these tools vs. actual data from industry) were not provided but would be required to determine the accuracy of the cost estimates.

Recommendation #2 - Without divulging proprietary information, these software and databases should be described with respect to the following:

- What the software does (i.e., input needed, type of embedded data, calculations performed, output provided).
- How embedded data in the software or the databases were developed.
- An explanation of how the software or databases have been validated.

This information is essential in order to evaluate the validity of the overall methodology.

Opinion #3 - The Applied Burden Rate generally results in labor costs that are many times higher than the direct labor costs. However, derivation and validation of the values used in the equation for calculating Applied Burden Rate were not clearly described in the report. Without knowing the derivation and validation of these values, the accuracy of the cost estimates cannot be determined. (Page 99 - Appendix F.1)

Recommendation #3 - Details regarding the derivation and validation of the values used in the equation for calculating the Applied Burden Rate should to be fully explained in the report.

Opinion #4 - Four components comprise 58% of the total cost. The four components appear to be classified as high cost items, but marketplace crosschecks from suppliers were not obtained, even though marketplace crosschecks were described as a part of the methodology. Without marketplace crosschecks from suppliers, the accuracy of the cost estimates cannot be determined. The four components are:

1.	Fuel pump	$69.61
2.	Fuel injectors	$52.49
3.	Turbocharger	$151.85
4.	PCM	$40.00
	Total of 4 items	$313.95 (out of $537.70 total)

Recommendation #4 – Perform marketplace crosschecks for components classified as high cost items to establish the validity of the cost estimates of these items.

Opinion #5 -The following issues with the methodology are expected to directly affect the accuracy of the cost estimates:

1. OEM's and suppliers are assumed to have the manufacturing facilities and equipment for the new technologies (Page 16). Issue: Components comprising the core of the new technology will probably be incremental and require new manufacturing facilities and equipment.
2. All manufacturing processes and operations are assumed to be based on standard/mainstream industrial processes (Page 16). Issue: New technology is likely to involve new, non-standard industrial processes.
3. No added vehicle costs were considered for the pilot study new technology (Page 18). Issue: The pilot study new technology is likely to require new or different vehicle installation hardware and the associated costs should be included in the overall costs.
4. The decisions to use either OEM or suppliers for manufacturing specific components were not clearly explained but appeared to be based on conventional practice and/or input from experts (Ref: conference call (9/21/09). Issue: Since OEM labor rates (direct

labor, fringe, and overhead) are significantly higher than supplier wage rates ($90.56/hr for OEM vs. $41.45 for T1 Supplier) (Page 42 (Figure 11), these decisions can significantly affect overall costs. The basis for these decisions should be clearly explained.

Recommendation #5 - Each of the above issues should be addressed and, where appropriate, revisions should be made to the methodology.

Opinion #6 - A number of issues with the methodology could potentially affect the accuracy of the cost estimates. For most of these issues, adequate information was not provided in the report to determine if these issues affected the costs. These issues are:

1. Different levels of maturity may be represented in the new technology vs. the base comparator technology (Page 12).
2. Different production volumes of the new technology engine (20,000 units per year) vs. the comparator baseline (840,000 units per year) may result in different design and manufacturing techniques (Page 73, Appendix B).
3. Different internal design and manufacturing practices may be represented in new technology vs. the comparator baseline technology if they are from different manufacturers.
4. For components not marked to show materials used in their manufacture, cross functional team members were consulted, and, if necessary, published information and experts in Tier 1 suppliers were consulted, instead of performing an analysis of the actual material (Page 34).
5. Material costs may be dependent on annual consumption rate. The methodology discusses the assignment of a low or high annual consumption rate pricing for a material (Page 34), yet this is not reflected in Figure 7 (Price Data for Significant Materials) (Page 32-33).
6. The method for determining the required material weights for the manufacturing processes, which would be higher than the finished part weights found in the teardown process, was not explained in the methodology in adequate detail (Page 26 and Appendix G).
7. The visual teardown inspection cannot capture many detailed specifications used in the manufacture of the part, such as tolerances of dimensions and fits or surface finishes/flatness requirements, which could add additional cost to the parts (Page 21).
8. Bureau of Labor Statistics (BLS) labor rates are used which are based on "union and non-union labor rates, reflecting the relative mix of each in the BLS motor vehicles and motor vehicle parts manufacturing classifications of the workforce at the time data was gathered (2007)"(Page 39). Using labor rates based on this mix may result in significant errors in labor costs.
9. "Two fringe rates were used: 52% for supplier manufacturing, and 160% for OEM manufacturing." "The OEM fringe rate was calculated using a 2006/2007 average North American wage rate and labor rate of $28.18 and $73.21 respectively…." "The supplier manufacturing fringe rate is based on historical knowledge" (Page 40).
10. Warranty data on the new technology and the comparator baseline should have been examined to ensure that comparable design methodologies were used to ensure comparable useful lives. Without ensuring comparable useful lives, costs may not be comparable.
11. Differences between components contained in the new technology and comparator baseline that are not directly related to the technology need to be analyzed to determine

the proper handling of these differences in the methodology (e.g., balance shaft (with/without), close coupled catalyst (with/without), fabricated/cast camshaft).

Recommendation #6 - Each of these issues should be addressed and, where, appropriate, resolved within the methodology.

Opinion #7 - Several important steps were suggested in the methodology. However, the conference call (9/21/09) indicated that these steps were not followed which might potentially affect the accuracy of the cost estimate. These steps are:

1. The methodology described the process of subjecting a part with high or unexpected cost results to a marketplace crosscheck for validation (Page 15 Step 8). However, the conference call indicated that this step had not been performed.
2. The CBOM chart (next to last column) has a provision for accounting for design modifications for MCR. However, the conference call (9/21/09) indicated that this was not done (Page 19 and Page 75, CBOM).
3. The CBOM chart (last column) shows the possible accounting for NTA, which provides alternative, advanced technology ideas, which could be substituted for some existing hardware being evaluated. However, the conference call (9/21/09) indicated that this was not done (Page 19 and Page 75, CBOM).

Recommendation #7 – Since these steps were described in the methodology, they should be followed, unless an explanation of why they were not followed is provided. Otherwise, they should be removed as part of the methodology.

Opinion #8 - Other concerns were identified that could potentially affect the accuracy of the cost estimates determined by the methodology. These include:

1. Issues with the application of the new technologies in five vehicle size classes (Page 9).
2. Qualifications and experience of the cross functional team that reviews all data from the teardown (Page 13, Step 5).
3. Intellectual property is often an important part of new technology powertrains, but was not addressed in the methodology.
4. Production testing (e.g., leak testing of fuel rails, end of line engine testing) may be required for some components or systems, but was not addressed in the methodology.
5. The analysis assumed an annual volume of 450,000 units. However, due to recent severe fluctuations in the automotive market, volume sensitive costs should be provided.

Recommendation #8 – Each of these concerns should be resolved and, where appropriate, incorporated into the methodology.

In addition to the above opinions, the following subsections are also provided in the Discussion section:

B. Other Comments on the Report

1. Issue with fuel economy comparison between new technology and comparator baseline due to differences in vehicle weights (Page 12 and Appendix B.1 (Page 73))

2. Issue with different emission certification levels of the new technology (Tier 2, Bin 5) vs. the baseline Partial Zero Emission Vehicle (PZEV), which is considerably more stringent (Appendix B.1 (Page 73)).

C. Recommendations to Improve the Study and/or Report

D. Wording or Spelling Issues

Discussion

A. Specific Opinions

Note: Opinions are repeated from the previous Specific Opinions and Recommendations section.
Note: Major Recommendations are provided only in the previous Specific Opinions and Recommendations section.
Note: Some detailed recommendations are provided only in this Discussion section and are underlined for clarity

Opinion #1 – This methodology is designed to determine incremental, direct manufacturing costs for new technology vs. comparator baseline technology. Incremental, direct manufacturing costs are only part of the price to society for new technology.

EPA recently developed a modified multiplier, referred to as an ICM, which specifically evaluates the components of indirect costs that are likely to be affected by vehicle modifications associated with environmental regulations (Ref: EPA Report "Automobile Industry Retail Price Equivalent and Indirect Cost Multiplier", EPA-420-R-09-003, February 2009. These multipliers were derived for low, medium and high technology complexity and for short-term effects and long-term effects. The appropriate multiplier should be applied to the direct manufacturing cost to determine the price of the new technology to society.

Opinion #2 - The methodology makes extensive use of proprietary software and databases, which are not available for peer review. Without detailed information regarding these proprietary tools, the accuracy of the cost estimates cannot be determined. The following proprietary tools are used in the methodology:

1. Lean Design software developed by Munro & Associates is used for mapping high-level processes and calculating complete process times (Page 13 (Step 4) and Page 105 (Appendix F.1)).

Page 13 (Step 4) states that the Lean Design software developed by Munro & Associates is used for high-level process mapping (Step 4 and Page 105 (Appendix F.1)) and for capturing all steps associated with the assembly of components. Without an explanation of what the software does, how embedded data was developed and how the software was validated, the accuracy of the cost estimates cannot be determined.

Page 14 states that output from the process maps created by Lean Design are imported into the MAQS.

Page 105 (Appendix F.1) states that "total serial process time", which is "referenced to mass production assumption calculations", must be entered into the Lean Design software. To assess the accuracy of the cost estimates, an explanation of the source and validity of the "total serial process time" input data and the meaning of "referenced to mass production assumption calculations" would be required. Since "total serial process time" would appear to require knowledge of the details of the manufacturing processes, the <u>source of this information should be provided</u>.

2. Design Profit software is utilized to map high-level modules within each system/subsystem (Page 21) and all secondary processes (page 26) and contains maps and costing databases used as input to the MAQS (Page 14, Page 21, Page 26, and Page 27 (Figure 4)).

Page 14 states that Design Profit software contains maps and costing databases used as input to the MAQS.

Pages 21 and 26 state that, in the high level teardown, "high level modules within each system/subsystem" are mapped into the Design Profit software. In the second level teardown, all steps associated with assembly of the components are captured in Design Profit software. Details of the Design Profit software were not disclosed in the report. Munroe and Associates was assumed to be the developer based on their name appearing in the subsequent Figure 3(Page 24) showing subassembly properties.

Figure 4 (Page 27), which shows process mapping for the cylinder head, provides some insight into the input required for the Design Profit software. However, without knowing the details of what the Design Profit software does, how it determines the times required for each step of the process (e.g., historical data base, analytical model, etc.) and how the software results were validated, the impact of this step on the <u>accuracy of the cost estimates cannot be determined</u>.

The methodology needs to explain how Lean Design software is related to Design Profit software. Both appear to be used for high-level process mapping while Design Profit appears to be used to map secondary processes, but only Lean Design is mentioned in Appendix F.1 (page 105) MAQS Worksheet Task Reference Guide. The methodology needs to clarify how the Lean Design input to the MAQS (Page 14) differs from the Design Profit input into the MAQS (Page 14).

Page 21 states that components are put through Munro & Associates' "internal costing tools to develop serial manufacturing process times". An explanation of what tools are being used should be provided. If these tools are in addition to Lean Design and Design Profit, without a further, detailed explanation of these tools, the <u>accuracy of the cost estimates cannot be assessed.</u>

3. "An applicable database" is used to provide "surrogate costs" when a part is treated as a "buy" (page 19).

Page 19 states in the case where a part is a "buy", "surrogate costs are pulled from an applicable database". Without a detailed description of this "applicable data base" including how it was developed and how it was validated, the <u>accuracy of cost estimates cannot be determined</u>.

4. "Purchase Part Database" is used to provide values for commodity purchased parts (page 207, Appendix G.1-60 (4of4), Engine Electrical Systems – Engine Assembly MAQS spreadsheet).

As an example, Appendix G.1-60 (4of 4) (Page 207) states that a “Purchase Part Database” is used to provide values for commodity purchased parts. An explanation of how this database differs for the above “applicable database” should be provided. If this is a different database, then without a detailed description, the <u>accuracy of the cost estimates cannot be determined</u>.

5. Databases for material costs, labor rates, manufacturing overhead rates, mark-up rates, and packaging costs provide the foundation of the cost analysis (Page 30 and page 95, Appendix E.1-E.5). (These Appendices were provided separately on September 29, 2009, which limited the review time prior to the peer review submission date of October 5, 2009.)

Page 30 states that Appendix E.1-E.5 (page 95) contains the cost analysis, which includes databases for material costs, labor rates, manufacturing overhead rates, mark-up rates, and packaging costs. “The databases provide the foundation of the cost analysis since all costs originate from them…”.

The separately provided spreadsheets did not appear to be labeled as Appendix E.1 – E.5. Instead, they were labeled by topic as follows: Labor, Mark-up, Manufacturing Overhead (MOH), Packaging Description, and Raw Materials.

<u>Recommendation:</u> These Appendices should be labeled so that the designations E.1-E.5 are clearly associated with the respective topic. Subsequent references in this peer review will be by topic (e.g., E.Labor) for clarity.

Comparing Figure 6 (Page 31) with Appendix E.Labor shows a significant discrepancy. Figure 6 shows an AAF of –5% from 2008 to 2015. However, Appendix E.Labor shows an AAF of 0%. The effect of this discrepancy is significant as shown by the example below:

Electrical/Electronic Equipment Assemblers

	AAF	2008	2015
Figure 6	-5%	$29.69	$20.73
Appendix E. Labor	0%	$29.69	$29.69

Without knowing the labor rates that were actually used for 2015, the accuracy of a cost estimate for 2015 cannot be assessed.

<u>Recommendation:</u> This discrepancy in AAF and projected labor rates needs to be resolved before the report is published.

Some additional comments on Appendix E are addressed under Opinion #6.5.

<u>Opinion #3</u> - The Applied Burden Rate generally results in labor costs that are many times higher than the direct labor costs. However, derivation and validation of the values used in the equation for calculating Applied Burden Rate were not clearly described in the report. Without knowing the derivation and validation of these values, the <u>accuracy of the cost estimates cannot be determined</u>. (Page 99 - Appendix F.1)

Page 99 – The table in Appendix F.1 provides the following definition:

> The Applied Burden Rate = number of lines x parallel processing multiplier x burden rate.

The separately provided spreadsheets (as an example, the Turbocharging Assembly MAQS App G.1-15 (1 of 11) Page 1 of 4 lists all of the inputs to the above equation for each part. For Item 1A, Block Turbo Shaft Support – Cooling & Lub, as an example,

> Number of lines = 1
> Parallel processing multiplier = 8
> Burden rate = $30/hr
>
> The resulting Applied Burden Rate = $240/hr

Although the values used in the above equation are clearly shown on the referenced spreadsheet, the source or derivation and validation of the values were not clearly described in the report. Since the Applied Burden Rate has a major influence on the overall labor costs, the lack of adequate detail regarding the values used to calculate the Applied Burden Rate is a concern and could <u>potentially affect the accuracy of the cost estimate</u>.

Using the above example for Line 14 (Block Turbo Shaft Support – Cooling & Lub) of the spreadsheet, the specific concerns that need more detail are:

- 4 manual and 4 automatic stations are noted, which provide the parallel processor multiplier of 8. However, this implies that all 8 stations have labor associated with them.

  <u>Recommendation:</u> An explanation of why an "automatic" station needs a labor charge should be provided.

- The spreadsheet states that the "Lean Design calculation for complete process time" is 221 seconds, the tack time/machine/cycle is 20 seconds and the resulting pieces /hr is 177. The absence of the actual source or derivation and validation of these values is a concern and could <u>potentially affect the accuracy of the cost estimate</u>.

<u>Opinion #4</u> - Four components comprise 58% of the total cost. The four components appear to be classified as high cost items, but marketplace crosschecks from suppliers were not obtained, even though marketplace crosschecks were described as part of the methodology. Without marketplace crosschecks from suppliers, the <u>accuracy of the cost estimates cannot be determined</u>. The four components are:

1. Fuel pump $69.61

Page 234 Cost Model Analysis Template (CMAT) - for No. 11 - Fuel Induction Subsystem shows the fuel pump cost as $69.61 (from a full cost analysis). A marketplace crosscheck from suppliers would have helped to validate the accuracy of this cost.

2. Fuel injectors $52.49

Page 234 CMAT for No. 11 - Fuel Induction Subsystem shows the fuel injector cost as $52.49 (from a full cost analysis). A marketplace crosscheck from suppliers would have helped to validate the accuracy of this cost.

3. Turbocharger $151.85

Page 246 CMAT for No. 15 - Induction Air Charging Subsystem shows the turbocharger cost as $151.85. A marketplace crosscheck from suppliers would have helped to validate the accuracy of this cost.

4. PCM $40.00

Page 252 and No. 60 - Engine Electrical Systems Spreadsheet provided separately shows the differential cost of the PCM as a Supplier Accounted Cost (SAC) of $40.00. This cost is shown as a "Purchase Part – Commodity" with value taken from Purchase Part database. Appendix C (page 91) states, "Estimated cost from Tech Team on GDI PCM may cost $40-45 more than a PFI PCM". For a component that comprises approximately 7% of the total incremental cost of the new technology, a more detailed analysis of this cost would be expected. Costs for incremental changes to the PCM should be detailed and may include changes to the following:

Input/output requirements
Drivers (conference call (9/21/09) indicated that these were the only items considered)
RAM memory requirements
ROM memory requirements
CPU requirements

Page 91 CBOM states that the PCM hardware is carryover except for the PFI drivers. The GDI drivers use 75-80 V DC boost circuit and 25 A peak/hold drivers, which are presumed to be responsible for the incremental $40 cost. Page 91 CBOM also states that the low side driver for the turbocharger is "really no cost". However, cost for this low side driver may be incurred if a low side driver together with output pins and connector are not available within the baseline PCM.

"Since the software is described as "much more complicated", it is not clear why there were no changes in any of the above items except for the drivers to accommodate the more complicated software.

Other concerns with the cost analysis for the PCM are as follows:

- An explanation of the Purchase Part database is needed (which was not explained in the report).
- Why was the PCM classified as a commodity, since Powertrain Control Modules are typically not considered a commodity?
- A supplier quote would have helped to validate this cost.

<u>Opinion #</u>5 -The following issues with the methodology are expected to <u>directly affect the accuracy of the cost estimates</u>:

1. OEM's and suppliers are assumed to have the manufacturing facilities and equipment for the new technologies (Page 16). Issue: Components comprising the core of the new technology will probably be incremental and require new manufacturing facilities and equipment.

Page 16 (Item 2) states that OEM's and suppliers have manufacturing equipment and facilities capable of handling required manufacturing processes and capacities, unless otherwise stated. This assumption may not be valid in most cases since the manufacturing facilities and equipment for the new technologies probably do not exist since components comprising the core of the new technologies will be incremental. For example, introduction of 450,000 units of the 1.6L DI turbo charged (TC) engine will result in incremental requirements for turbochargers, DI fuel pumps, DI injectors and other unique components for this technology. Not accounting for these incremental facilities and equipment costs would directly affect the accuracy of the cost estimates.

2. All manufacturing processes and operations are assumed to be based on standard/mainstream industrial processes (Page 16). Issue: New technology is likely to involve new, non-standard industrial processes.

Page 16 (Items 3 and 4) state that "All manufacturing processes and operations are based on standard/mainstream industrial processes" and that supplier mark-up rates are based on mature technology and manufacturing processes unless otherwise specified." Some processes in the automotive industry are unique today and it is likely that new technology, especially in the battery area, will involve non-standard industrial processes. Not accounting for these unique processes may directly affect the accuracy of the cost estimates.

3. No added vehicle costs were considered for the pilot study new technology (Page 18). Issue: The pilot study new technology is likely to require new or different vehicle installation hardware and the associated costs should be included in the overall costs.

Page 18 states "no added cost considered for new technology (1.6L TC DI vs. 2.4L NA)". This statement appears to refer to vehicle installation added costs. However, a downsized, turbocharged engine may require some additional items for the vehicle installation, such as:

- Heat shields to protect vehicle components from the higher temperatures of the turbocharger
- Changes to the engine mounting system. Since the downsized engine will be operating at higher specific loads, vibration forces may be increased at typical operating conditions and a revised engine mounting system may be required to minimize the transmission of these forces.
- Wiring changes to accommodate the added PCM inputs and outputs.
- Possible additional sound insulation to offset higher average specific loads of a downsized engine.

Not accounting for these unique processes may directly affect the accuracy of the cost estimates.

4. The decisions to use either OEM or suppliers for manufacturing specific components were not clearly explained but appeared to be based on conventional practice and/or input from experts (Ref: conference call (9/21/09). Issue: Since OEM labor rates (direct

labor, fringe, and overhead) are significantly higher than supplier wage rates ($90.56/hr for OEM vs. $41.45 for T1 Supplier) (Page 42 (Figure 11), these decisions can significantly affect overall costs. The basis for these decisions should be clearly explained.

Figure 11 (Page 42) appears to show that the average total labor rate (direct labor + indirect labor + MRO (Maintenance, Repair, Other) + fringe) for a supplier (Motor Vehicle Parts Manufacturing) is $41.45 and for an OEM (Motor Vehicle Manufacturing) is $90.56. Appendix F.1 (Page 96) shows that OEM/T1 classification is an input to MAQS worksheet; however, a description of how the OEM/T1 classification was determined was not provided. The conference call (9/21/09) indicated that the OEM/T1 classification decision was based on FEV's internal and external contacts. More detail on this decision, which influences labor cost by a 2:1 factor, should be provided since this decision directly affects the accuracy of the cost estimates.

Opinion #6 - A number of issues with the methodology could potentially affect the accuracy of the cost estimates. For most of these issues, adequate information was not provided in the report to determine if these issues affected the costs. These issues are:

1. Different levels of maturity may be represented in the new technology vs. the base comparator technology (Page 12).

The selection of vehicles that represent the base and new technology cases for the teardown and cost analysis (Page 12) may have different levels of maturity. The new technology may not have benefited from years of cost reductions in the base technology, which could potentially affect the accuracy of the cost estimates.

2. Different production volumes of the new technology engine (20,000 units per year) vs. the comparator baseline (840,000 units per year) may result in different design and manufacturing techniques (Page 73, Appendix B).

The selection of vehicles that represent the base and new technology cases for the teardown and cost analysis (Page 12) may have different production volumes. Higher volumes for the new technology may result in different design and manufacturing techniques, which could impact costs.

Page 73 (Appendix B) shows that the new technology 1.6L TC DI engine has a volume of 20,000 units whereas the baseline 2.4L NA has a volume of 840,000 units. The exceptionally low volume of the new technology engine is a significant concern since it may not represent the design and manufacturing techniques that would be used for a high volume engine, and, thus, potentially affect the accuracy of the cost estimates.

This effect will be even more critical for more advanced, new technologies such as lithium-ion batteries. In the September 2009 issue of "Ward's Autoworld", Ric Fulop, founder of A123 Systems, Inc., stated that in the next decade lithium-ion batteries will double in energy density and cut costs in half.

3. Different internal design and manufacturing practices may be represented in new technology vs. the comparator baseline technology if they are from different manufacturers.

The new technology may be from a different manufacturer than the base technology. As a result, different internal practices may be represented which could <u>potentially affect the accuracy of the cost estimate</u>.

4. For components not marked to show materials used in their manufacture, cross functional team members were consulted, and, if necessary, published information and experts in Tier 1 suppliers were consulted, instead of performing an analysis of the actual material (Page 34).

Page 34 (Material Identification) states that," For components that are not marked, cross-functional team members are consulted to help in the materials identification. For any materials still not identified, information published in print and on the web is researched, or primary manufacturers and experts within the Tier 1 supplier community are contacted to establish credible material choices." This is not a rigorous method for determining material used in a specific part from a teardown. A more reliable method would have been to conduct an analysis of the actual material from the part. Not having an analysis of the actual material forming a part is a concern, and could <u>potentially affect the accuracy of the cost estimate</u>.

5. Material costs may be dependent on annual consumption rate. The methodology discusses the assignment of a low or high annual consumption rate pricing for a material (Page 34), yet this is not reflected in Figure 7 (Price Data for Significant Materials) (Page 32-33).

An indication of whether low or high annual consumption rate pricing was applied for specific materials is provided in Appendix E.Raw Materials.

<u>Recommendation:</u> The text of the report should state that the application of either low or high annual consumption rate pricing for a specific material could be found in Appendix E.Raw Materials.

The report also states that Appendix E.Raw Materials provides the "Information Reference Source". However, a number of materials were listed without this information being provided under "Information Reference Source".

<u>Recommendation:</u> All materials used in this study should be included in Appendix E.Raw Materials and the "Information Reference Source" should be provided for each of these materials.

Most of the "Information Reference Sources" listed were either publicly available websites and magazines or the comment, "Composition analysis plus surcharge". Confirmation of the pricing with supplier quotes was not apparent in the Appendix. Not having at least selective supplier quotes is a concern and <u>could potentially affect the accuracy of the cost estimate.</u>

<u>Recommendation:</u> At least selected high annual consumption rate materials should have been confirmed with supplier quotes.

<u>Recommendation:</u> An explanation of "composition analysis plus surcharge" should be provided and explained in the text.

6. The method for determining the required material weights for the manufacturing processes, which would be higher than the finished part weights found in the teardown

process, was not explained in the methodology in adequate detail (Page 26 and Appendix G).

Appendix G – Material Cost - Material cost appears to be derived by multiplying the component part weight by the material cost per lb. (example page 149). However, manufacturing processes typically require a quantity of material, which is larger than the finished part since the manufacturing processes involve metal removal or casting waste. The derivation of material weights, which would be higher than the finished part weights, should be explained since the resulting material weights could potentially affect the accuracy of the cost estimates.

Page 26 states that "the overall size of the part in bar or rod form prior to machining" is determined without specifying how this was done. The conference call (9/21/09) explained that the weight of the bar or rod vs. the observed teardown weight is used throughout the methodology. The report should provide some examples of the differences in these two weights so that the validity of the method used to determine the differences could be assessed.

Recommendation: The process for determining the overall size of the part in bar or rod form prior to machining should be explained.

7. The visual teardown inspection cannot capture many detailed specifications used in the manufacture of the part, such as tolerances of dimensions and fits or surface finishes/flatness requirements, which could add additional cost to the parts (Page 21).

Page 21 – "All attributes of the parts are captured, including assembly characteristics, materials, quantities, weights…" However, this type of visual tear down inspection cannot capture specifications, such as tolerances on dimensions and fits or surface finishes/flatness requirements. The manufacturer of these parts may use extra or unique processes to achieve the tolerances and requirements that result in satisfactory function of the components, subsystems or system. For example, Appendix D (Page 93-94), which lists some of the operational symbols in Design Profit, do not include honing operations used in cylinder bore finishing or lapping used in injector manufacturing. Achieving these specifications often requires additional costs that could potentially affect the accuracy of the cost estimates.

8. BLS labor rates are used which are based on "union and non-union labor rates, reflecting the relative mix of each in the BLS motor vehicles and motor vehicle parts manufacturing classifications of the workforce at the time data was gathered (2007)"(Page 39). Using labor rates based on this mix may result in significant errors in labor costs.

Using labor rates based on a mix of union and non-union labor rates for 2007 could potentially affect the accuracy of the cost estimates. There would be significant errors in labor costs on the low side by applying a mixed labor rate to a fully unionized supplier. Conversely, there would be significant errors in labor rates on the high side by applying a mixed labor rate to a non-unionized supplier. A further justification for using this technique should be provided since it could potentially affect the accuracy of the cost estimates.

Due to the severe restructuring in the automotive industry in 2008 and 2009, the labor rates should be updated since they could potentially affect the accuracy of the cost estimates.

9. "Two fringe rates were used: 52% for supplier manufacturing, and 160% for OEM manufacturing." "The OEM fringe rate was calculated using a 2006/2007 average North

American wage rate and labor rate of $28.18 and $73.21 respectively….” “The supplier manufacturing fringe rate is based on historical knowledge” (Page 40).

The 2006/2007 burden data for OEM’s may be obsolete as a result of the many changes in the automotive industry in 2008 and 2009 and should be updated. The update could potentially affect the accuracy of the cost estimates.

10. Warranty data on the new technology and the comparator baseline should have been examined to ensure that comparable design methodologies were used to ensure comparable useful lives. Without ensuring comparable useful lives, costs may not be comparable.

If high warranty costs were encountered in the new technology, this would indicate inadequate designs, materials or processes were used. To ensure that the new technology and comparator baseline have comparable useful lives (i.e., durability), upgrades may need to be applied to the new technology. These upgrades to achieve a comparable useful life could potentially affect the accuracy of the cost estimates.

11. Differences between components contained in the new technology and comparator baseline that are not directly related to the technology need to be analyzed to determine the proper handling of these differences in the methodology (e.g., balance shaft (with/without), close coupled catalyst (with/without), fabricated/cast camshaft).

As an example (Page 76 (CBOM for the Counterbalance System)), the CBOM states “Balance shaft not required on turbo DI due to smaller engine size.” Likewise, the Subsystem CMAT, Appendix H.1.04) shows negative incremental costs for the balance shaft subassembly for the new technology (and zero actual costs, Appendix H.1.04 SubCMAT spreadsheet provided separately). Before this conclusion could be reached, the unbalance forces of the turbo DI engine without a balance shaft should be calculated to demonstrate that their levels were no worse than the comparator baseline engine (with balance shaft) at typical vehicle operating conditions.

As another example (Page 86 (CBOM for the Exhaust Systems – Catalysts), the CBOM indicates that a close-coupled catalyst will be used on the new technology. The CBOM has a comment that “Close coupled catalytic converter not a requirement for turbo DI technology”. This comment does not appear to be based on test data and therefore, should be deleted for the following reason. Generally, the industry has found that close-coupled catalysts are required to ensure rapid catalyst light-off for today’s NA engines to meet the current, stringent emission standards. When a turbocharger is applied, the turbocharged acts as a heat sink, which would slow down the catalyst light-off process, thereby tending to increase emissions. Therefore, since the NA engine has a close-coupled catalyst (identified as a common item), then the turbo DI technology should also have the close-coupled catalyst and may even require additional technology to meet the same emission standard as the NA engine.

A third example, discussed during the conference call (9/21/09), concerned camshafts. The new technology turbo DI engine had an assembled camshaft, but the comparator baseline had a cast camshaft. However, for the incremental cost comparison, both engines were assumed to have cast camshafts. These differences could not be found in the CBOM (Page 81).

Recommendation: The report should clearly define and justify the components that were substituted in the analysis (vs. the observed teardown parts) since such changes can potentially affect the accuracy of the cost estimates.

Opinion #7 - Several important steps were suggested in the methodology. However, the conference call (9/21/09) indicated that these steps were not followed which might potentially affect the accuracy of the cost estimate. These steps are:

1. The methodology described the process of subjecting a part with high or unexpected cost results to a marketplace crosscheck for validation (Page 15 Step 8). However, the conference call indicated that this step had not been performed.

As mentioned on Page 15 (Step 8) subjecting parts with high or unexpected cost results to a marketplace crosscheck such as comparison with supplier price quotes is an excellent step for validating the methodology. However, the conference call (9/21/09) indicated that this step was not taken. Not taking this validation step could potentially affect the accuracy of the cost estimate.

2. The CBOM chart (next to last column) has a provision for accounting for design modifications for MCR. However, the conference call (9/21/09) indicated that this was not done (Page 19 and Page 75, CBOM).

The baseline technology has probably been exposed to MCR actions over a number of years whereas the new technology has not benefited from similar MCR actions. Not accounting for potential MCR actions in the new technology, as well in the baseline technology, and ensuring that comparable MCR actions are applied to both could potentially affect the accuracy of the cost estimate.

As an example, see Page 75 (CBOM), for the crankshaft, the CBOM states under “Design Modifications for Material Cost Reduction (MCR)”, “Potential for base engine crankshaft to be made from nodular cast iron as a cost save. However, the conference call (9/21/09) indicated that this potential MCR action was not taken into account in the cost analysis.

3. The CBOM chart (last column) shows the possible accounting for NTA, which provides alternative, advanced technology ideas, which could be substituted for some existing hardware being evaluated. However, the conference call (9/21/09) indicated that this was not done (Page 19 and Page 75, CBOM).

As an example, the CBOM (Page 90) suggests the possibility of unit cost savings by switching from a conventional air-to-air charge air cooler to a water-to-air charge air cooler, although the tooling bill would be higher. Not considering potential new technology advances could potentially affect the accuracy of the cost estimate.

Opinion #8 - Other concerns were identified that could potentially affect the accuracy of the cost estimates determined by the methodology. These include:

1. Issues with the application of the new technologies in five vehicle size classes (Page 9).

Page 9 of the report states that, “…application of new technologies in five vehicle size classes is considered”, but no details are provided. Significant differences can be encountered in different vehicle size classes. In the pilot study, a larger, naturally aspirated I4 engine is replaced with a similar, but downsized turbocharged I4 engine. However, as an example, the results for the pilot study would not apply to larger vehicles in which a NA V6 engine would be replaced with a downsized turbocharged I4 engine. In this case, there is a significant change in the engine configuration from V6 to I4, which would need to be accounted for in the analysis. Each of the five vehicle size classes would require a detailed analysis to account for such changes which could <u>possibly affect the accuracy of overall costs</u>.

2. Qualifications and experience of the cross functional team that reviews all data from the teardown (Page 13, Step 5).

The make-up of the cross-functional team that reviews all of the data from the high level teardown is critical (Page 13 (Step 5)). The qualifications and experience of the cross-functional team members, which would be expected to affect the quality of the reviews, should be provided in the report. The qualifications and experience of the team could <u>possibly affect the accuracy of overall costs</u>.

3. Intellectual property is often an important part of new technology powertrains, but was not addressed in the methodology.

New technology is likely to involve intellectual property, such as patents, know-how and trade secrets. When new technology is developed by one leading company, other companies will need to negotiate a license to use the technology. The cost methodology did not appear to have a means for accounting for the cost of intellectual property, which could <u>possibly affect the accuracy of the cost estimates</u>.

4. Production testing (e.g., leak testing of fuel rails, end of line engine testing) may be required for some components or systems, but was not addressed in the methodology.

Some production parts require functional testing in addition to the usual quality control inspections. One such part is the fuel rail, which might require leak testing. In addition, end of line testing of the entire engine assembly (hot or cold) is usually required and would be more complex for a turbocharged engine.

Note that the critical testing required for balancing the turbocharger rotor was recognized with respect to the labor cost (Item 5A, Appendix G.1-15 (1 of 11) provided separately). Inadequate information was provided to determine if the machining required to actually balance the turbocharger rotor was also included.

The methodology does not appear to uniformly recognize this type of testing, which could <u>possibly affect the accuracy of the cost estimates</u>.

5. The analysis assumed an annual volume of 450,000 units. However, due to recent severe fluctuations in the automotive market, volume sensitive costs should be provided.

The methodology does not appear to recognize the impact of severe fluctuations in the automotive market, which could possibly affect the accuracy of the cost estimates. The analysis assumes an average annual volume of 450,000 units (Page 10). The basis of this assumption should be provided. Because of the recent severe fluctuations in the automotive market and specific automotive segments, providing a volume sensitive cost would be helpful.

B. Other Comment on the Report

1. Issue with fuel economy comparison between new technology and comparator baseline due to differences in vehicle weights (Page 12 and Appendix B.1 (Page 73)).

Page 12 and Appendix B.1 (Page 73) – The comparison of fuel economy for the new technology and comparator baseline vehicle is flawed because the new technology is applied to a significantly lighter vehicle (2668 lbs) vs. the baseline technology (3310 lbs), which is a difference of 642 lbs.

2. Issue with different emission certification levels of the new technology (Tier 2, Bin 5) vs. the baseline (PZEV), which is considerably more stringent (Appendix B.1 (Page 73)).

The methodology does not appear to take into account the costs required to reduce emissions of the new technology to the level of the baseline.

Recommendation: The costs required to ensure comparable certification emission levels for the new technology and the baseline should be accounted for in the methodology.

C. Recommendations to Improve the Study and/or Report:

1. A glossary of terms needs to be provided before this report with its complexity is released.

2. Each of the appendices should to be listed in the Table of Contents

3. Some of the appendices have the format of “Appendix F.1”. However, an Appendix F.2, etc. does not appear to exist. Therefore, a better designation for the appendices is recommended to avoid searches for appendices that do not exist.

4. Page 8 – For ease of cross-referencing, the numbering used for the subsystems throughout the analysis should be used on the summary chart showing the incremental costs.

5. Page 13 – The convention adopted in this report of referring to a “quote” as the “analytically-determined cost of a part or assembly, not a price provided by a supplier”, is very misleading. Common terminology is that a quote is a price provided by a supplier. An analytically determined cost should be called an “analytically determined cost” in the report.

D. Wording or Spelling Issues:

Page 31, last line – “…in the cast study analysis.” should be changed to “…in the cost study analysis.”

Page 35, Section 6.2.3, line 6 – “…Metalprices, estainlesssteel…” should be changed to “…metal prices, stainless steel…”

Page 36, Section 6.2.4, paragraph 2, line 1 and Figure 9 - “Figure 9 illustrates the power curve…” should be changed to “Figure 9 illustrates the price curve…”

Page 45, line 1 – “…establish the reference the baseline…” should be changed to “…establish the reference baseline…”

Page 52, line 2 – “…same level of mark-up is applied regardless the…” should be changed to “…same level of mark-up is applied regardless of the…”

Page 58, last paragraph, line 4 – “…manufacturing costs are capture for the…” should be changed to “..manufacturing costs are captured for the…”.

Page 58, last paragraph, next to the last line – “Alternatively in single a MAQS…” should be changed to “Alternatively in a single MAQS…”

Page 61, first paragraph under Section 9.3, line 4 – “…interactions tacking place…” should be changed to “…interactions taking place…”

Appendix F - Curricula Vitae of Selected Peer Reviewers

Dionissios (Dennis) N. Assanis

PERSONAL

Degrees

Ph.D., Power and Propulsion, Massachusetts Institute of Technology (M.I.T.), 1985
M.S., Management, Sloan School of Management, M.I.T., 1986
M.S., Mechanical Engineering, M.I.T., 1982
M.S., Naval Architecture and Marine Engineering, M.I.T., 1982
B.Sc., Marine Engineering, Newcastle University, England, 1980

Positions at University of Michigan

Jon R. and Beverly S. Holt Professor of Engineering
Arthur F. Thurnau Professor of the University of Michigan
Director, Michigan Memorial Phoenix Energy Institute, 2009-date
Chair, Mechanical Engineering, Jan. 2002- Aug. 2007
Professor of Mechanical Engineering, Sept. 1994-date
Professor of Applied Physics, 2003-date
Director, Automotive Research Center, Sept. 2000-date
Founding Co-Director, General Motors Collaborative Research Laboratory on Engine Systems Research, 2002-2013
Director, W. E. Lay Automotive Laboratory, 1996-date
Associate Director, General Motors Satellite Research Laboratory, 1998-2002
Deputy Director, Automotive Research Center, Jan. 1996-Aug. 2000
Acting Director, Automotive Research Center, Aug.1995- Dec. 1995
Interim Director, CoE Interdisciplinary Professional Programs, Fall 2001
Founding Director, CoE Automotive Engineering Program, Sept. 1999-Apr. 2002
Founding Director, MEAM Automotive Engineering Program, 1995-1999

Positions at University of Illinois in Urbana-Champaign

Associate Professor of Mechanical Engineering, Aug. 1990 - Aug. 1994
Head, Thermal Sciences/Systems Division II, Aug. 1992 - Aug. 1994
Research Scientist, Office for Supercomputing Applications, Aug. 1991- 1994
Assistant Professor of Mechanical Engineering, Sept. 1985 - Aug. 1990

Positions at Other Institutions

Honorary President, Zhejiang Automotive Engineering Institute, 2009
Honorary Professor, Zhejiang Automotive Engineering Institute, 2009
Advisory Professor, Shanghai Jiao Tong University, Shanghai, China, 2009
Guest Professor, Shanghai Jiao Tong University, Shanghai, China, 2003-2008
Adjunct Research Scientist, Argonne National Laboratory, Energy and Environmental Systems Division, May 1987-2002
Research Assistant, Sloan Automotive Laboratory, Massachusetts Institute of Technology, Sept. 1982- Aug. 1985

Teaching and Research Assistant, Department of Ocean Engineering, Massachusetts Institute of Technology, Sept. 1980-June 1982

Honors and Awards

University of Michigan Rackham Distinguished Faculty Achievement Award, 2009
Member, National Academy of Engineering, 2008
ASME, Internal Combustion Engine Award, 2008
ASME Fellow, 2008
Jon R. and Beverly S. Holt Professor of Engineering, 2000
Tau Beta Pi Professor of the Year Award, 2006
SAE Award for Research on Automotive Lubricants, 2002
SAE Fellow, 2001
ASEE Annual Distinguisher Lecturer, College of Engineering, The University of Michigan, April 12, 2000
Teaching Excellence Award, College of Engineering, The University of Michigan, 2000
Arthur F. Thurnau Professor, The University of Michigan, 1999
Excellence in Teaching Award, Mechanical Engineering and Applied Mechanics, The University of Michigan, 1998
ASME Internal Combustion Engine Division Meritorious Service Award, 1997
ASME Internal Combustion Engine Division Speaker Award, 1993
ASME Internal Combustion Engine Division Speaker Award, 1994
Listed in *Who's Who in America*, 1994-date
Listed in *Who's Who in Science and Engineering*, 1993-date
Listed in *American Men and Women of Science*, 1992-date
University of Illinois Scholar, 1991 - 94
SAE Russell Springer Award, 1991
IBM Research Award, 1991
ASME/Pi Tau Sigma Gold Medal Award, 1990
NSF Presidential Young Investigator Award, 1988-93
Lilly Endowment Teaching Fellow Award, 1988
NSF Engineering Initiation Award, 1987
NASA Certificate of Recognition for Creative Development of a Technical Innovation, 1987
SAE Ralph Teetor Award to Outstanding Young Educators, 1987
Excellent Teacher, listed every semester in student newspaper *The Daily Illini*, 1985-94
Honors, B.Sc. Degree with Distinction, 1980

CONTRIBUTIONS TO ACADEMIC LEADERSHIP AND SERVICE

Contributions as Chair of Mechanical Engineering

As Chair of the Department of Mechanical Engineering (ME) at the University of Michigan (2002-2007), Professor Assanis led the administration and long-range development of the ME Department's academic and research programs. The ME Department is a major academic unit that is educating more than 700 undergraduate students and 500 graduate students (250 Master's and 250 Ph.Ds), and employing 55 tenured and tenure track professorial faculty members, 18 primary research scientists and 70 support staff members in a physical plant of approx. 120,000 square feet spread out over four buildings. Throughout his tenure as ME Chair, the Department's undergraduate and graduate programs were consistently ranked within the top five nationally by U.S. News and World Report. His efforts have made significant contributions in the following areas:

- Planned strategically to establish and articulate a shared vision for the future that sustains and evolves the ME Departments core academic and research strengths in automotive and manufacturing engineering, while also developing a competitive position into the emerging areas of mechanical engineering, including bio-systems, energy/ eco-systems and micro/nano-systems. As the culmination of these strategic planning efforts, a major addition and remodeling of the ME Building facilities, has emerged as the #2 all-campus building priority for UM's capital outlay plan over the next five years.
- Successfully retained the ME Departments excellent body of faculty and hired outstanding new faculty (11 new Professors and 15 Research Scientists). Promoted in rank 27 faculty members, including 5 women faculty who reached the rank of Professor. In addition to assessing and rewarding the performance of professorial faculty, implemented procedures for the annual review and merit raises of primary research faculty. Mentored junior faculty members in their professional careers and made a deliberate effort to address issues that could compromise their success. Nominated a number of colleagues, students, alumni and staff who received prestigious professional awards, both outside and within the University, including four new endowed chairs.
- Enhanced the ME Departments efforts to create a multi-cultural and diverse intellectual environment by retaining all women and underrepresented minority (URM) faculty; by hiring thee more women faculty members for a total of 10 (18% of ME faculty); by strategically recruiting URM and women students through K-12 programs, the Detroit Area Pre-College Engineering Program, and the NSF Research Experience for Undergraduates Program; and by supporting mentorship groups including Unified Minority Mechanical Engineers and Society of Women Engineers. Improved communications among the students, alumni, faculty and staff.
- Oversaw financial planning, budgets and expenditures for the ME Department (annual budget of approx. $14M in general funds and more than $28M in research funds and gifts) and introduced "paperless" electronic tools in the areas of student services, financial reporting, and faculty recruiting. Participated in fundraising and pubic relations efforts for the ME Department and College of Engineering in close coordination with the development staff. Through these efforts, new endowed professorships, a number of undergraduate student scholarships, and new graduate fellowships from industry, and a prestigious named lectureship series about the role of the *Engineer in Society* have been attracted to the ME Department.
- Made significant progress towards a "paperless" administration through the development and implementation of electronic solutions in the areas of student services (with web-based graduate application and admissions tracking systems), financial reporting (with accounting statements for contracts on line), faculty recruiting and faculty data center.
- Promoted the systematic exchange of faculty and students with strategically selected global partners, notably with the Shanghai Jiao Tong University, the Korean Advanced Institute for Science and Technology, Seoul National University and the Technical University of Berlin.
- Enhanced the strong tradition of an active and engaged External Advisory Board (EAB) which has served as a model for other CoE Departments and the University of Michigan's Transportation Research Institute (UMTRI).

- Promoted the development of K-12 programs intended to spark the interest of the brightest youngsters - including women and traditionally underrepresented groups in math, science and engineering.

Contributions as Director of Automotive Engineering Program

As the Founding Director of the Master's of Engineering Program in Automotive Engineering (AUTO), I was responsible for designing the curriculum and launching the new degree Program, first in the Department of Mechanical Engineering and subsequently as a College-wide program in the College of Engineering. My responsibilities have included recruiting prospective students, advising all M. Eng. students, developing new courses, and pursuing international collaborations for joint degree offerings with global Universities, and especially Aachen (Germany) and Loughborough (UK) as part of the Ford Global Automotive Systems Master's degree. As part of our curriculum improvement activities, I founded the College of Engineering AUTO Council and led its efforts to develop and evolve a strong academic curriculum that meets industry needs. I also worked very effectively with the UM Center for Professional Development to offer to industry a distance-learning version of our M.Eng. Program. Our visionary pursuit of distance learning teaching has set a standard for other programs to emulate.
Overall, I strived to grow our AUTO program, while simultaneously improving the quality of the entering students and courses offered. Our goals were met with great success, as evidenced by the enrollment in the AUTO program, which exceeded 100 students within 5 years from the program's introduction, and the excellent job placement and very positive feedback expressed by many of our continuing students and graduates.

Contributions as Interim Director of Interdisciplinary Professional Programs

As the Interim Director of the College of Engineering's Interdisciplinary Professional Programs (INTERPRO), I provided stability and leadership during a period of transition and growth to six interdisciplinary programs, automotive engineering, financial engineering, integrated micro-systems, manufacturing engineering, pharmaceutical engineering, and plastics engineering. During my tenure as Director and working with the INTERPRO Directors' Council, I oversaw the management of the large growth in student enrollment which reached an all time high (320 enrolled students) in the history of the INTERPRO programs. Most of this growth was accounted by part-time, distance learning professionals. I stepped down from my role as INTERPRO Director and AUTO Program Director to assume the position of Chair of Mechanical Engineering.

OTHER CONTRIBUTIONS TO SERVICE

Major Committee Assignments at University of Michigan

UM Energy Council, Founding Member, 2003-date

> *Charter member of the team that actively pursued the development of a UM research thrust on Energy working in partnership with other Colleges, articulated the vision statement for the thrust, and recommended to the UM administration the development of a University-wide Energy Laboratory at the site of the decommissioned nuclear reactor.*

College of Engineering (COE) Budget Task Team, 2005-07, Member

COE Center of Professional Development Executive Committee, 2005-06, Member

COE Faculty Fellows Program, October 11-12, 2002, Panelist

President’s Committee on Intellectual Property Policy, 2001-02, Member

COE Interdisciplinary Professional Program Directors Committee, 2001, Chair

COE Nominating Committee, 2000-2001, Chair

COE Automotive Council, 1999-date, Chair

COE Curriculum Committee, 2000, Member

University Senate, 1995-98, Elected Senator

ME (formerly MEAM) Advisory Committee,

Elected Member 1995-96, 1997-98 and Fall 2001
Chair, 2002-to date

ME (formerly MEAM) Planning Committee

Member, 1997-98
Chair, 2002 to date

MEAM Thermal Science Instructional Area Coordinator, 1997-2000

COE Committee on Reshaping Graduate Education at the Master’s Level, 1998-99, Member

COE Committee on M. Eng. Programs, 1998-99, Member

COE UM-National University of Singapore Committee on Establishment of Joint MEng Program in Automotive Engineering, 1997-98, Chair

COE Committee on Faculty Incentives for Continuing Education (ICE) and Distance Learning Instruction, 1997-98, Member

MEAM Space Task Force Committee, 1996-98, Member

W. E. Lay Automotive Laboratory Test Cell Committee, 1994-present, Chair

W. E. Lay Automotive Laboratory Renovations Committee, 1994-95, Member

MEAM Laboratory and Safety Committee, 1995-1998, Member

Service to Other Organizations

1. External Boards

Member, External Advisory Board, Department of Mechanical Engineering, Georgia Tech, 2004-date.

Member, Global External Advisory Board, Department of Mechanical Engineering, Korean Advanced Institute for Science and Technology (KAIST), 2006-2008.

Member, External Validation Panel for Launching MSc degree in Automotive Engineering Design, Hong Kong Polytechnic University, 2007.

Chair, King Abdullah University of Science and Technology (KAUST) Search for Director of Center for Clean Combustion Energy, 2008-09.

Incoming Member, ASME Internal Combustion Engine Division Executive Committee, 2008-13.

Member, National Academy of Sciences Committee on Fuel Economy of Medium- and Heavy-Duty Vehicles, appointed by the National Research Council’s Board on Energy and Environmental Systems, 11/08-5/31/10.

Co-Chair, National Academy of Engineering Annual German-American Frontiers of Engineering GAFOE Symposium, 2010-2012.

Chair, Advisory Board, Tula Technology, 2009-date.

2. Editorships

Editor, International Journal of Automotive Technology, 2008-2011
Associate Editor, ASME Journal for Gas Turbines and Power, 1996-2007
Editorial Board, International Journal of Engine Research, 2003-2012
Editorial Board, International Journal of Automotive Technology, 2005-2008
Scientific Board, Ingineria Automobilului, 2007-date
Guest Editor, International Journal of Heavy Vehicle Systems, 2004

3. Professional Society Memberships

American Society of Mechanical Engineers, Fellow

Executive Committee Member, ICE Division, 2008-2013
Journal Associate Editor, 1996-2008
Past Chair of Student Activities, ICE Division

Society of Automotive Engineers, Fellow

Member, SAE Research Executive Committee, 2000-date
Faculty Advisor, University of Michigan, 1996-2004
CoE Future Car, Faculty Co-Advisor, 1997-98
Member, Advanced Powerplant Committee
Member, Passenger Car Readers Committee
Member, Vehicular Heat Exchanger and Heat Transfer Committee

American Society for Engineering Education, Member

Sigma Xi, Member

New York Academy of Sciences, Member

The Combustion Institute, Member

Society of Naval Architects and Marine Engineers, Associate Member

4. Organizing and Chairing Conferences, Sessions, Workshops, Lectures

Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 12-13, 2009

Organizer, 2ns Annual Michael E. Korybalski Endowed Lecture in Mechanical Engineering: “Size Matters,” given by Dr. Roger McCarthy, Emeritus Chairman and CEO, Exponent, Inc., May 4, 2009

Chair, Prime Power, National Defense Industrial Association – Michigan Chapter, Power and Energy Workshop, Troy, MI, November 18-19, 2008

Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2008

Member of Scientific Committee, International Workshop on Advances in Combustion Science and Technology, India Institute of Technology, Kanpur, India, Dec. 31, 2007- Jan. 8, 2008

Organizer, Inaugural Michael E. Korybalski Endowed Lecture in Mechanical Engineering: “Driving to a Sustainable Future, a New DNA for the Automobile,” given by Dr. Lawrence Burns, VP Research, Development and Planning, General Motors

Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2007.

Member of Scientific Committee, 2nd International Symposium on Clean and Efficient Combustion Engines, Tianjin, China, July 10-13, 2006.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2006.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2005.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2004.
Co-Organizer, “Premixed Charge Compression Ignition Engines,” 2003 JSAE/SAE International Spring Meeting, Yokohama, Japan, May 19-22, 2003.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2003.
Co-Organizer and Chair, “Homogeneous Charge Compression Ignition Engines,” 2003 SAE World Congress, Detroit, MI, March 3-6, 2003.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May, 2002.
Organizer, “Homogeneous Charge Compression Ignition Engines,” 2002 SAE International Spring Fuels & Lubricants Meeting, Reno, Nevada, May 6 - 8, 2002.
Co-Organizer, “Advanced Hybrid Powertrain Systems,” 2002 World Congress, Detroit, MI, March 4-7, 2002.
Co-Organizer, “Homogeneous Charge Compression Ignition Engines,” 2002 World Congress, Detroit, MI, March 4-7, 2002.
Co-Organizer and Chair, “Homogeneous Charge Compression Ignition Engines,” ASME Fall Technical Conference, Argonne, IL, Sep. 23-26, 2001.
Co-Organizer, “Homogeneous Charge Compression Ignition Engines,” SAE 2001 Fall Fuels and Lubricants International Conference, San Antonio, TX, September 24-27, 2001.
Member, Advisory Committee, COMODIA 2001, *International Symposium on Diagnostics and Modeling of Combustion in Internal Combustion Engines*, Nagoya, Japan, July 1-4, 2001.
Organizer and Chair, “Homogeneous Charge Compression Ignition Engines,” SAE 2001 Spring Fuels and Lubricants International Conference, Orlando, Florida, May 7-9, 2001.
Chair and Co-Organizer, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 15-16, 2001.
Co-Organizer and Co-Chair, “Hybrid Electric Vehicles,” SAE International Congress and Exhibition, March 5-8, 2001.
Co-Organizer and Chair, “Novel SI and CI Combustion Systems,” SAE 2000 Fuels and Lubricants International Conference, Paris, France, June 19-22, 2000.
Co-Organizer and Session Chair, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 2000.
Co-Organizer, “Direct Injection Engines and Sprays,” ASME-ICE Sprint Technical Conference, San Antonio, TX, April 9-12, 2000.
Co-Organizer, “Homogeneous Charge Compression Ignition Engines,” SAE International Fuel and Lubricants Meeting, Toronto, Canada, Oct. 25-28, 1999.
Organizer, “Modeling and Simulation of Direct Injection Engine Processes,” ASME-ICE Fall Technical Conference, Ann Arbor, MI, Oct. 16-20, 1999.
Host, ASME-ICE Fall Technical Conference, Ann Arbor, MI, Oct. 16-20, 1999.
Member of Technical Program Committee, Vehicle Thermal Management Systems VTMS-4 International Conference, London, UK, May 24-26, 1999.

Co-Organizer and Session Chair, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 1999.

Organizer, “Modeling and Simulation of Engine Combustion Processes,” ASME-ICE Spring Technical Conference, Columbus, IN, April 24-28, 1999.

Organizer, “Advanced Diesel Engine Powertrains,” SAE International Congress and Exposition, Detroit, MI, Feb. 23-26, 1999.

Organizer, “Modeling and Simulation of Engine Combustion Processes,” ASME-ICE Fall Technical Conference, Clymer, New York, September 27-30, 1998.

Moderator, “The Future of Automotive Systems,” SAE Automotive Systems Testing Topical Technical Symposium (TOPTEC), Novi, MI, October 14-15, 1998.

Co-Organizer and Session Chair, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 1998.

Chair, Panel on Surface Engineering and Tribology, SAE International Congress and Exposition, Detroit, MI, Feb. 23-26, 1998.

Organizer, “Adiabatic and Miller Cycle Engines,” SAE International Congress and Exposition, Detroit, MI, Feb. 23-26, 1998.

Organizer, “New Analytical Methods in Engine Design,” ASME-ICE Fall Technical Conference, Madison, WI, Sept. 27 - Oct. 1, 1997.

Co-Organizer and Session Chair of ARC Annual Conference, “Critical Technologies in Modeling and Simulation of Ground Vehicles,” June 3-4, 1997.

Member of Technical Program Committee, Vehicle Thermal Management Systems VTMS-3 International Conference, Indianapolis, IN, May 19-22, 1997.

Organizer, “New Analytical Methods in Engine Design,” ASME-ICE Spring Technical Conference, Fort Collins, Colorado, April 27-30, 1997.

Co-Organizer, "Adiabatic Engines", SAE International Congress and Exposition, Detroit, MI, 1997. Member, Program Review Subcommittee, Twenty-Sixth International Symposium on Combustion, Naples, Italy, July 28-Aug. 2, 1996.

Co-Organizer and Session Chair, ARC Annual Conference, “Critical Technologies for Modeling and Simulation of Ground Vehicles,” May 29-30, 1996.

Organizer, Student Paper Competition, ASME ICE Fall Technical Conference, Fairborn, OH, Oct. 20-23, 1996.

Co-Organizer and Chairman, “Engine Simulations,” ASME ICE Fall Technical Conference, Fairborn, OH, Oct. 20-23, 1996.

Co-Organizer, “Adiabatic Engines,” SAE International Congress and Exposition, Detroit, MI, 1996. Organizing Committee, Fraunhofer Institute-University of Michigan Joint Conference, “The Best of German/American Automotive Technology,” Southfield, MI, June 27-28, 1995

Co-Organizer and Chairman, “Engine Simulations,” ASME Engine Technology Spring Conference, Marietta, Ohio, April 23-26, 1995.

Co-Organizer and Session Chair of ARC Annual Conference, “Critical Technologies in Modeling and Simulation of Ground Vehicles,” April 19-20, 1995

Co-Organizer, “Adiabatic Engines,” SAE International Congress and Exposition, Detroit, MI, 1995.

Chairman and Co-Organizer, “Modeling Engine Processes,” ASME Fall Technical Conference, Lafayette, IN, 1994. Chairman and Co-Organizer, “Adiabatic Engines,” SAE International Congress and Exposition, Detroit, MI, 1994.

Chairman and Organizer, “Engine Design,” Energy Technology Conference and Exhibition, New Orleans, LA, 1994.

Chairman and Co-Organizer, "Engine Simulation and Controls," ASME Fall Technical Conference, Morgantown, WV, 1993.

Co-Chairman, "Engine Sprays," ILASS, Worcester, MA, 1993. Chairman, “Vehicle Cooling Systems,” International Conference on Vehicle Thermal Management Systems, Columbus, OH, 1993.

Chairman and Co-Organizer, “Adiabatic Engines,” SAE International Congress and Exposition, Detroit, MI, 1993.

Vice-Chairman and Co-Organizer, “Intake Air Management,” Energy Technology Conference and Exhibition, Houston, TX, 1993.

Chairman and Co-Organizer, “Adiabatic Engine Components,” Vice-Chairman, “High Temperature Engine Heat Transfer,” SAE International Congress and Exposition, Detroit, MI, 1992.

Vice-Chairman and Co-Organizer, “Engine Simulation,” Energy Technology Conference and Exhibition, Houston, TX, 1992.

Co-Organizer, “Panel on Post-95 Low Emission Engines,” ASME Energy Technology Conference and Exhibition, Houston, TX, 1991.

Moderator and Co-Organizer, “Panel on Post-95 Low Emission Engines,” SAE International Congress and Exposition, Detroit, MI, 1991.

Chairman and Co-Organizer, “Adiabatic Engine Components,” Vice-Chairman, "High Temperature Engine Heat Transfer," SAE International Congress and Exposition, Detroit, MI, 1991.

Chairman and Co-Organizer, “Adiabatic Engine Components,” Vice-Chairman, "High Temperature Engine Operation," SAE International Congress and Exposition, Detroit, MI, 1990.

Vice-Chairman, “Basic Engine Processes,” Energy Technology Conference and Exhibition, Houston, TX, 1989.

Chairman and Co-Organizer, “Adiabatic Engine Components,” Vice-Chairman, "High Temperature Tribology," SAE International Congress and Exposition, Detroit, MI, 1989.

Vice-Chairman and Co-Organizer, “International Symposium on Flows in Reciprocating Internal Combustion Engines,” ASME Winter Annual Meeting, Chicago, IL, 1988.

Vice-Chairman, “Basic Engine Processes,” American Society of Mechanical Engineers, Energy Technology Conference and Exhibition, New Orleans, LA, 1988.

Assistant Chairperson, “High Temperature Tribology,” SAE International Congress and Exposition, Detroit, MI, 1988.

Chairman, “Engine Simulation Studies,” International Association for Vehicle Design Fourth International Congress, Genera, Switzerland, 1987.

Assistant Chairperson, “Adiabatic Engines,” SAE International Congress and Exposition, Detroit, MI, 1987.

5. Service as Consultant to Government and Industry

Assanis and Associates, Inc., President, Ann Arbor, MI (2000-date)
Optimetrics, Inc., Ann Arbor, MI (1999)
Textron Automotive, Southfield, MI (1998)
M.A.N.A.G.E., Inc., President, Ann Arbor, MI (1995-1998)
Automated Analysis Corporation, Ann Arbor, MI (1996)
Mobil Technology Company, New Jersey (1996-1997)
GM Electromotive Division, La Grange, IL (1988-1992)
National Aeronautics and Space Administration, Cleveland, OH (1988)

Adiabatics, Inc., Columbus, IN (1986-1991)
Science Application International Corp., Seattle, WA (1986-1987)

CONTRIBUTIONS TO EDUCATION

Sustained Commitment to Education

I have sustained my passionate commitment to education for over 20 years. As an Assistant and Associate Professor at the University of Illinois at Urbana-Champaign, I have taught a range of thermal science courses with student evaluations of my teaching consistently placing me at the very top in a group of 50 faculty members. After joining the University of Michigan, my teaching evaluations (4.74/5.0 average for the quality of the courses I have taught and 4.85/5.0 for the effectiveness of my teaching) have continued to be among the highest in the Mechanical Engineering Department (55 tenured or tenure track faculty) and the College of Engineering (more than 320 faculty members).

In 1987, I was honored with the Society of Automotive Engineers Ralph Teetor Award, given to 20 outstanding engineering educators nationwide each year. In 1988, I was one of six young UIUC faculty members selected in campus-wide competition to receive Lilly Teaching Fellow Awards. In 1990, I received the American Society of Mechanical Engineers/Pi Tau Sigma Gold Medal Award given annually in nationwide competition to the best mechanical engineer 10 years after graduation. In 1991-94, I was named University of Illinois Scholar for my contributions to research and teaching. I am truly gratified to have been honored with the 1997-98 MEAM Excellence in Teaching Award, the 2000 College of Engineering Teaching Excellence Award, the distinguished Arthur F. Thurnau Chaired Professorship, and as the inaugural recipient of the Jon R. and Beverly S. Holt Chaired Professorship.

Teaching Philosophy

I have always felt that a successful educator must love teaching and be able to convey excitement for learning to his/her students. Many of my activities as a teacher and mentor are governed by my strong belief that the key to effective teaching is to be enthusiastic about your teaching and to genuinely care about passing your knowledge to your students. I personally strive to show my students my own excitement about the material and to motivate them to make a sincere effort to master the subject. I have always emphasized the importance of an engaging and interactive teaching-learning process, and created an open and informal atmosphere in the class that encourages students to ask or answer questions. I have taken some bold steps to shift the paradigms of teaching theoretical concepts to engineers, infused my own scholarly activities into the classroom and shared my teaching techniques with my colleagues and future educators. I have stressed my belief that the only way to learn a subject is through hard work and application of your knowledge to real projects, and repeatedly found that students will work hard as long as they are motivated, encouraged when they face adversity and rewarded for their intellectual accomplishments.

Beyond the traditional classroom teaching, I have adopted a holistic approach to the teaching/learning process and utilized effectively the time outside the classroom to advise, mentor, coach and teach the students. This is particularly important in the case of younger students who have not yet crystallized their interests for their lifetime pursuits. Good advice and broadening of their perspective can have a critical impact in their future careers. I have also greatly enjoyed being the Faculty Advisor of the student chapters of the Society of Automotive

Engineers and the American Society of Mechanical Engineers, working with the various student project teams, helping them in their fundraising efforts, and addressing their technical and administrative needs. Getting to know the undergraduate students better and contributing to their education outside the classroom through special projects is time consuming, but can be extremely rewarding to both the students and the teacher.

Teaching Innovations

I am particularly proud of the new perspective I have brought to the student teaching and learning process. The traditional way of teaching undergraduate courses in thermo-sciences and their applications to energy conversion and internal combustion engines has been through lectures and the use of highly idealized models. These ideal models inherently make crude assumptions so that results are often far from reality. Without compromising teaching of the fundamentals, I have introduced an innovative approach to further the education of my students through the incorporation and coordinated use of a series of hands-on laboratories, computer simulation tools, scientific movies, and real life case studies that are presented within and in parallel with the lectures. Sophisticated laboratory experiments and realistic simulation programs provide a more complete understanding of the important physical processes. Students can use the simulation models to compare and analyze their experimental data under similar operating conditions, and suggest ways to improve either the simulation models or the experimental techniques.

In my continuing efforts to enrich the class content, I have also relied on the use of the internet and distance learning. With my graduate student instructors, we have developed integrated learning environments, posted under http://meonline.engin.umich.edu/, that can be used asynchronously, and at the student's learning pace, to bring together lecture notes, the blackboard, assignments, solutions, clipboards, laboratory demos, simulation runs and engine movies in digital media. We are now planning to run laboratory experiments live from the classroom, or for that matter from any internet connection, to enable students to appreciate lecture content and theory in the light of reality with live demonstrations. Through these innovative approaches, I constantly strive to add another dimension to the student learning.

Infusion of Scholarly Contributions into Teaching-Learning Process

My teaching interests parallel and complement my research interests, as my philosophy is that an excellent teacher must be at the same time a leader in his field of research. Only this way I feel I can give my students the best and most relevant education to enable them become leaders in their fields. In the course of my group's research activities, we have developed a large body of engine simulation software that is extensively used by automotive manufacturers in engine development. With the ever-increasing capabilities of personal computers and graphical programming languages such as C++ and MATLAB-SIMULINK, it has become possible to infuse user-friendly, student versions of these computer simulations to the classroom, thus greatly contributing to my effective teaching. My research activities have also enabled me to rejuvenate the Walter Lay Automotive Laboratory, thus contributing advanced engine experiments to our classes and exposing our students to state-of-the-art laboratory set-ups (http://me.engin.umich.edu/autolab/). These activities have contributed to reaffirming U of M's leadership in automotive engineering.

Contributions to New Course Development

Although the University of Michigan has had a long tradition of excellence in the instruction of internal combustion engines, when I started my career as a Professor at Michigan I realized that our engine-related courses and research facilities were not adequate to meet the current demands of the industrial and research communities for automotive engineers. In order to give our students the best possible education in the field, I have taken a series of steps. First, I completely revised the lectures of our undergraduate/beginner graduate course (ME 438) in internal combustion engines. In addition, I developed and incorporated a series of laboratories as part of the course, which was thus converted from three to four credit hours. This course enrollment has almost doubled in size following my revisions, and has been offered simultaneously via distance learning to industry. Second, based on my scholarly activities, I developed a graduate level course (originally ME 534 and now renumbered as ME538) that deals with the application of thermal sciences to the simulation and design of modern combustion engines. Third, I have developed with my undergraduate and graduate students a single-cylinder engine laboratory experiment that has been used as part of our thermal science laboratory class.

As part of my activities as the Director of the Automotive Program, I oversaw the development of the curriculum for the new degree program and contributed a number of the new modules that were essential to achieving the goals M.Eng. program. In order to broaden the horizons of automotive engineers, I introduced a two semester sequence of automotive seminars (ME 591 and ME 592, now renumbered as ME 501), delivered by industry leaders, that exposed the students to the wide spectrum of interdisciplinary engineering activities involved in the process of development, design, and manufacturing of complex automotive systems. In one of its offerings, the UM automotive seminar class was focused on Vehicle Energy, in global collaboration with Aachen University, Germany, and Ford Motor Company. Furthermore, to provide our automotive engineering students with practical experience in team building, carrying out projects in interdisciplinary teams, and in developing and managing projects, I introduced the capstone M.Eng. Automotive project (ME 593, now renumbered as ME 502). The Automotive Seminars and Project experiences we provide our students have been a model for similar “practimum” programs introduced by several Departments in the College of Engineering.

Courses Taught at University of Michigan

Date	Course	Course Title	Enroll	Crs Eval	Instr Eval
Winter 95	ME 534	Advanced Internal Combustion Eng.	23	4.45	4.54
Fall 95	ME 438	Internal Combustion Engines	42	4.85	4.85
Winter 96	ME 534	Advanced Internal Combustion Eng.	21	4.87	4.97
Winter 96	ME 592	Automotive Eng. Seminar II	8	n/a*	n/a
Fall 96	ME 438	Internal Combustion Engines	69 (43+26)**	4.83	4.85
Fall 96	ME 591	Automotive Eng. Seminar I	18	n/a	N/A
Winter 97	ME 534	Advanced Internal Combustion Eng.	18	4.86	4.94
Winter 97	ME 592	Automotive Eng. Seminar II		n/a	n/a

Date	Course	Course Title	Enroll	Crs Eval	Instr Eval
Fall 97	ME 438	Internal Combustion Engines	68 (37+31)	4.80	4.88
Fall 97	ME 591	Automotive Eng. Seminar I	12	n/a	n/a
Winter 98	ME 534	Advanced Internal Combustion Eng.	32	4.17	4.72
Winter 98	ME 592	Automotive Eng. Seminar II	40 (15+25)	n/a	n/a
Fall 98	ME 438	Internal Combustion Engines	50	4.86	4.94
Fall 98	ME 591	Automotive Eng. Seminar I		n/a	n/a
Winter 99	ME 592	Automotive Eng. Seminar II		n/a	n/a
Fall 99	ME 438	Internal Combustion Engines	88 (53+35)	4.83	4.95
Fall 99	ME 591	Automotive Eng. Seminar I	33 (18+15)	n/a	n/a
Winter 00	ME 534	Advanced Internal Combustion Eng.	23	4.71	4.85
Winter 00	ME 592	Automotive Eng. Seminar II (Vehicle Energy Seminar)	38 (23+15)	n/a	n/a
Fall 00	ME 591	Automotive Eng. Seminar I	33 (18+15)	n/a	n/a
Fall 01	ME 438	Internal Combustion Engines	66 (41+25)	4.85	4.90
Fall 01	ME 591	Automotive Eng. Seminar I	40 (15+25)	n/a	n/a
Fall 02	ME 438	Internal Combustion Engines	53	4.85	4.85
Fall 03	ME 438	Internal Combustion Engines	72 (32+40)	4.97	4.97
Fall 04	ME 438	Internal Combustion Engines	54	4.91	4.93
Fall 05	ME 438	Internal Combustion Engines	70 (50+20)	4.88	4.88
Fall 06	ME 438	Internal Combustion Engines	50	4.92	4.91
Winter 08	ME 599	Analysis and Control of Alternative Powertrains	26 (20+6)		
Fall 08	ME 438	Internal Combustion Engines	40	4.94	4.94
Wint 09	ME 538	Advanced ICEs	32		

* Organizer and host of Automotive Engineering Seminar Series I and II. Standard course evaluation forms not applicable (n/a).
** Distribution designates student enrollment for on-campus and distance learning students.

Offerings of Short Courses and Workshops

I am a proponent of life-long learning and have frequently taught short courses and workshops to practicing engineers in industry. Examples are:

"Modeling and Computer Simulation of Internal Combustion Engines," Chair, Continuing Engineering Education, University of Michigan, September 9-13, 1996; July 7-11, 1997; June 29-July 3, 1998; July 5-9, 1999; July 10-14, 2000.

“Basic Engines and Their Controls,” Chair, Continuing Engineering Education, Motorola, Deerfield, IL, two-day offerings, 1996-2005.

One-on-One Student Instruction and Mentorship

Ph. D. Committees Chaired at University of Michigan

1. Xiaobo Sun, 1996, Chair
2. George Papageorgakis, 1997, Chair
3. Apoorva Agarwal, 1998, Chair
4. Dohoy Jung, 2000, Chair
5. George Delagrammatikas, 2001, Co-Chair (with P. Papalambros)
6. Sang-Jin Hong, 2001, Co-Chair (with M. Wooldridge)
7. Scott Fiveland, 2001, Chair
8. Stani Bohac, 2002, Chair
9. Kukwon Cho, 2003, Co-Chair (with Z. Filipi)
10. Guntram Lechner, 2003, Chair
11. Christopher Depcik, 2003, Chair
12. Bruno Vanzieleghem, 2004, Co-Chair (with H. Im)
13. Pin Zeng, 2004, Chair
14. Wooheum Cho, 2004, Chair
15. Junseok Chung, 2004, Co-Chair (with Z. Filipi)
16. Tim Jacobs, 2005, Chair
17. Aris Babajimopoulos, 2005, Chair
18. Ron Grover, 2005, Chair
19. Christos Chryssakis, 2005, Chair
20. Bin Wu, 2005, Co-Chair (with Z. Filipi)
21. Sangseok Yu, 2006, Co-Chair (with D. Jung)
22. Vassilis Hamosfakidis, 2006 (Chair)
23. Kyoung Joon Chang, 2007, Chair
24. Alex Knafl, 2007, Chair
25. Manbae Han, 2007, Co-Chair (with S. Bohac)
26. Melody Papke, 2007, Co-Chair with Jun Ni
27. Andreas Malikopoulos, 2007, Co-Chair (with P. Papalambros)
28. Jonathan Hagena, 2007, Co-Chair (with Z. Filipi)
29. Robert Prucka, 2007, Co-Chair (with Z. Filipi)
30. Orgun Guralp, 2008, Co-Chair (with Z. Filipi)
31. Chaitanya Sampara, 2008, Co-Chair (with E. Bissett, GM)
32. Yanbin Mo, 2008, Chair
33. Shawn Grannell, 2008, Co-Chair (with S. Bohac)
34. Andrew Ickes, 2009, Co-Chair (with S. Bohac)
35. Hee Jun Park, 2009, Co-Chair (with D. Jung)
36. Seung Hwan Keum, 2009, Co-Chair (with H. Im)
37. Byungchan Lee, candidate, 2009 (expected), Co-Chair (with Z. Filipi)
38. Jason Martz, candidate, 2009 (expected), Chair
39. Will Northrop, candidate, 2009 (expected), Co-Chair (with S. Bohac)
40. Michael Smith, candidate, 2010 (expected), Chair
41. Matt Spears, pre-candidate, 2010 (expected), Chair
42. Sung Jin Park, pre-candidate, 2010 (expected), Co-Chair (with D. Jung)
43. Jerry Fuschetto, pre-candidate, 2010 (expected), Chair

44. Russel Truemner, pre-candidate, 2011(expected), Co-Chair (with M. Parsons)
45. Stefan Klinkert, pre-candidate, 2011 (expected), Co-Chair (with S. Bohac)
46. Mehdi Abarham, pre-candidate, 2011 (expected), Co-Chair (with J. Hoard)
47. Robert Middleton, pre-candidate, 2012 (expected), Chair
48. Kevin Zasek, pre-candidate, 2012 (expected), Co-Chair (with Z. Filipi)
49. Sotiris Mamalis, pre-candidate, 2012 (expected), Co-Chair (with A. Babajimopoulos)
50. Vishnu Nair, pre-candidate, 2012 (expected), Co-Chair (with A. Babajimopoulos)
51. Janardhan Kodavasal, pre-candidate, 2012 (expected), Co-Chair (with A. Babajimopoulos)
52. Ashwin Salvi, pre-candidate, 2012 (expected), Co-Chair (with Z. Filipi)

Ph. D. Committees Chaired at University of Illinois in Urbana-Champaign

1. Qiong Li, 1991, Chair
2. Leonard Shih, 1992, Chair
3. Panos Tamamidis, 1992, Chair
4. Constantine Varnavas, 1994, Chair
5. Douglas Baker, 1995, Chair
6. Michalis Syrimis, 1996, Chair

M. S. Committees Chaired at University of Michigan

1. James Wallace, 1997, Chair
2. Michael Mshar, 1998, Chair
3. Scott Fiveland, 1999, Chair
4. George Seaward, 2000, Chair
5. Chris Depcik, 2000, Chair
6. Salih Mahameed, 2001, Chair
7. Ron Grover, 2001, Chair
8. Selim Buyuktur, 2001, Co-Chair (with M. Wooldridge)
9. Cheol Su Lee, 2001, Chair
10. Brian Baldwin, 2001, Chair
11. Tim Jacobs, 2002, Chair
12. John Matsushima, 2002, Co-Chair (with Z. Filipi)
13. Aris Babajimopoulos, 2002, Chair
14. Christos Chryssakis, 2002, Chair
15. Berrin Daran, 2002, Co-Chair (with Z. Filipi)
16. Scott Thompson, 2003, Chair
17. Chad Jagmin, 2003, Co-Chair (with Z. Filipi)
18. Andrew Ickes, 2003, Chair
19. Matthew Leustek, 2003, Chair
20. Wesley Williamson, 2004, Co-Chair (with Z. Filipi)
21. Robert Prucka, 2004, Chair
22. Jonathan Hagena, 2004, Chair
23. Chaitanya Sampara, 2004, Chair
24. Orgun Guralp, 2004, Co-Chair (with Z. Filipi)
25. Gerald Fernandes, 2006, Co-Chair (with Z. Filipi)
26. Chandra Sandrasekaran, 2006, Co-Chair (with S. Bohac)
27. Steve Busch, 2007, Co-Chair (with S. Bohac)
28. Michael Smith, 2008, Chair

29. Alberto Lopez, 2008, Co-Chair (with S. Bohac)
30. Challa Prasad, 2008, Co-Chair (with A. Babajimopoulos)
31. Mark Hoffman, 2008, Co-Chair (with Z. Filipi)
32. Robert Middleton, 2009 (expected), Chair
33. Ashwin Salvi, 2009 (expected), Co-Chair (with Z. Filipi)
34. Anastasios Amoratis, 2009 (expected), Chair
35. Jeremy Spater, 2009 (expected), Chair
36. Sotiris Mamalis, 2009 (expected), Chair
36. Laura Manofsky, 2009 (expected), Chair
37. Samuel Olesky, 2009 (expected), Chair
37. Janardhan Kodavasal, 2009 (expected, Co-Chair (with A. Babajimopoulos)
38. Elliott Alexander Ortiz Soto, 2009 (expected), Chair
39. Ben Lawler, 2010 (expected), Co-Chair (with Z. Filipi)
40. Ann Marie Lewis, 2010 (expected), Chair
41. Srinath Gopinath, 2010 (expected), Chair
42. Luke Hagen, 2010 (expected), Chair
43. Prasad Shigne, 2010 (expected), Co-Chair (with A. Babajimopoulos)

M. S. Degrees Chaired at University of Illinois in Urbana-Champaign

1. Edward Badillo, 1989, Chair
2. Matthew Polishak, 1989, Chair
3. Michael Bonne, 1989, Chair
4. James McLeskey, 1989, Chair
5. Riadh Namouchi, 1990, Chair
6. Tarun Mathur, 1990, Chair
7. Constantine Varnavas, 1990, Chair
8. Francis Friedmann, 1990, Chair
9. Andrew Phillips, 1990, Chair
10. Kevin Wiese, 1990, Chair
11. Brian Bolton, 1990, Chair
12. Panos Tamamidis, 1990, Chair
13. Thomas Leone, 1990, Chair
14. Timothy Burt, 1990, Chair
15. Douglas Baker, 1991, Chair
16. Gregory Clampitt, 1991, Co-Chair (with White)
17. Daniel Clark, 1991, Chair
18. Evangelos Karvounis, 1991, Chair
19. Matthew Lipinski, 1992, Co-Chair (with White)
20. Michalis Syrimis, 1992, Chair
21. Matthew Schroder, 1993, Co-Chair (with White)
22. Donald Nakic, 1994, Co-Chair (with White)
23. George Papageorgakis, 1994, Chair
24. Scott Butzin, 1994, Chair
25. Cristopher Bare, 1995, Chair
26. Thomas Brunner, 1995, Chair
27. Paul Herring, 1995, Chair
28. Stani Bohac, 1995, Chair
29. Timothy Frazier, 1995, Chair

M. Eng. Automotive Projects Directed at University of Michigan (ME 593/503, 4 credit hours)

1. Winter 1996; Fadi Kanafani
2. Winter 1996; Richard Sellschop
3. Spring 1996; Philip Glazatov
4. Spring 1996; David Silberstein
5. Fall 1996; Caleo Tsai
6. Fall 1997, Marc Allain
7. Winter 1997; Osvaldo Corona
8. Winter 1997; Fabien Redon
9. Winter 1997; Steven Siegal
10. Spring 1997; Eric Mokrenski
11. Winter 1998; Yu-Min Lin
12. Winter 1998; Faisal Mahroogi
13. Winter 1998; Bruno Vanzieleghem
14. Winter 1999; Stephanie Lacrosse
15. Winter 1999; Russell Thompson
16. Winter 1999; Carlos Armesto, Greg Christensen, Eugene Cox, John Dent
17. Winter 1999; John Joyce
18. Winter 1999; Marcus Branner
19. Winter 1999; Michael McGuire
20. Summer 1999; Steven Hoffman
21. Summer 1999; Bhargav SriParakash
22. Summer 1999; Alejandro Sales
23. Summer 1999; David Wheatley
24. Fall 1999; Todd Petersen
25. Fall 1999; John Matsushima
26. Fall 1999; Michelle Chaka and Mary Wroten
27. Fall 1999; Julie D'Annunzio, Timothy Veenstra, and Todd Glance
28. Winter 2000; Douglas Iduciani and Ronald Kruger
29. Winter 2000; Timothy Gernant, Allen Lehmen and Jeffrey Kaiser
30. Winter 2000; Brian Young, Mark Dipko and Andrew Slankard
31. Winter 2000; Stephen White
32. Winter 2000; Tomoyuki Takada, Mami Takada and Milton Wong
33. Winter 2000; Cristian Arnou and Soon Low
34. Spring 2000; Joseph Fedullo, Colin Roberts and John Celmins
35. Summer 2000; Frank Voorburg and Marie Mann
36. Winter 2001; Jason Martz;
37. Winter 2001; Kwang Yong Kang
38. Summer 2002; Jonathan Jackson
39. Summer 2002; David Swain and Dan Yerrace
40. Winter 2009; Peter Andruskiewicz
41. Winter 2009; Dan Murray 42.Winter 2009; Amit Goje

Diplomarbeit at Technical University of Graz, Austria
(carried-out at W. E. Lay Automotive Laboratory under my direction)
Guntram Lechner, 1999
Alex Knafl, 2001

Studenarbeit at Rheinisch-Westfalische Technische Hochschule Aachen
(carried-out at W. E. Lay Automotive Laboratory under my direction)
Michalis Panagiotidis, 1999
Christof Schultze, 1999

Graduate Special Projects (ME 590) Directed at University of Michigan

1. Winter 1995; Teresa Schulke; 3 credit hours
2. Winter 1995, Fadi Kanafani; 3 credit hours
3. Winter 1995, Karl Ondersma; 3 credit hours
4. Spring/Summer1995; M. Mubbashir Abbas; 2 credit hours
5. Winter 1996-98; Paul L. Powell III; 6 credit hours
6. Fall 1997; Kukwon Cho; 3 credit hours
7. Fall 1997; Erik Koehler; 3 credit hours
8. Winter 1998; Scott Fiveland; 3 credit hours
9. Winter 1999; Russell Thompson, 3 credit hours
10. Winter 1999; Stephanie LaCrosse, 3 credit hours
11. Summer 1999; Thomas Veling, 3 credit hours
12. Winter 2000, Carlos Armesto, 3 credit hours
13. Winter 2000, Lee Byungchan, 3 credit hours
14. Winter 2000 and Winter 2001, Cheol Su Lee, 6 credit hours
15. Winter 2000, Jeff Sanko, 3 credit hours
16. Winter 2000, Ryan Nelson, 3 credit hours
17. Winter 2000, Selim Buyuktur, 3 credit hours
18. Winter 2000, George Seaward, 3 credit hours
19. Winter 2000, Ping Yu, 3 credit hours
20. Fall 2000, Marie Mann, 3 credit hours
21. Fall 2000, Matthew Schwab, 3 credit hours
22. Winter 2002, Josh Richards, 3 credit hours
23. Winter 2002 and Fall 2002, Brett Thompson, 6 credit hours
24. Winter 2002, Mengkai Zhang, 3 credit hours
25. Fall 2003, Krishna Kumar, 3 credit hours
26. Fall 2003 and Winter 2004, Andreas Malikopoulos, 6 credit hours
27. Fall 2003 and Winter 2004, Christopher Morgan, 6 credit hours
28. Winter 2004, Mark Hoffman, 3 credit hours
29. Winter 2004, Weibin Zhu, 3 credit hours
30. Fall 2004, Seung Hwan Keum, 3 credit hours
31. Fall 2004, John Zeilstra, 3 credit hours
32. Fall 2004 and Winter 2005, Kwangsoon Choi, 6 credit hours
33. Fall 2004 and Winter 2005, Qi Wang, 6 credit hours
34. Fall 2004 and Winter 2005, Qingan Zhang, 6 credit hours
35. Fall 2005, Jarrod Robertson, 3 credit hours
36. Winter 2005, Stephen Busch, 3 credit hours
37. Winter 2005, Abigail Mechtenberg, 3 credit hours
38. Winter 2005, Richard Niedzwiecki, 3 credit hours
39. Winter 2007, David Ault; 3 credit hours
40. Winter 2007, Michael Christianson, 3 credit hours
41. Winter 2007, Matthew Fredo, 3 credit hours (with S. Bohac)
42. Winter 2007, Dong Han, 3 credit hours
43. Winter 2007, Stefan Klinkert, 3 credit hours (with S. Bohac)

44. Winter 2007, Mahesh Kumar Madurai. 3 credit hours
45. Winter 2007, Robert Middleton, 3 credit hours
46. Winter 2007, Ashutosh Sajwan, 3 credit hours (with S. Bohac)
47. Winter 2007, Jaskirat Singh, 3 credit hours (with D. Jung)
48. Fall 2007; Vivek Srinivasan Narayanan; 3 credit hours
49. Winter 2008, Ramamurthy Vaidyanathan; 3 credit hours
50. Spring 2008, Alphonso King, 6 credit hours
51. Fall 2008, Amit Goje, 3 credit hours
52. Fall 2008, Doohyun Kim, 3 credit hours
53. Fall 2008, Kyoung-Hyun Kwak, 3 credit hours
54. Fall 2008, Saktish Sathasivan, 3 credit hours
55. fall 2008, Prasad Shingne, 3 credit hours
56. Winter 2009, Sourabh Goel, 3 credit hours
57. Winter 2009, Chang-Ping Lee, 3 credit hours
58. Winter 2009, Kevin Zacek, 3 credit hours
59. Winter 2009, Elliott Ortiz-Sotto, 3 credit hours

Undergraduate Special Projects (ME 490) Directed at University of Michigan

1. Winter 1995, Maurice Moulton; 3 credit hours
2. Winter 1995; George Papageorgakis; 3 credit hours
3. Winter 1996; David Messih; 3 credit hours
4. Winter 1996; Eric Morenski; 3 credit hours
5. Winter 1996; Benedict J. Baladad; 3 credit hours
6. Winter 1996; Kevin Ferraro; 3 credit hours
7. Winter 1999; Nicholas Bellovary and Daniel Kulick, 3 credit hours
8. Winter 1999; Daniel Herrera and Joel Hartter, 3 credit hours
9. Winter 1999; Larry Mercier and Reza Sharifi, 3 credit hours
10. Winter 2000; Nicolas Wetzler, 3 credit hours
11. Winter 2001; Andrew Ickes, 3 credit hours
12. Winter 2002; Keith DeMaggio, 3 credit hours
13. Fall 2003; Marvin (Bob) Riley
14. Fall 2004; Katherine Chia-Chun Ho, 3 credit hours
15. Fall 2004, Liang Xue, 3 credit hours
16. Winter 2005, Levi Roodvoets, 3 credit hours
17. Fall 2005; Erin Robbins, 3 credit hours
18. Winter 2006; David Ault, 3 credit hours
19. Winter 2006; Tommaso Gomez, 3 credit hours
20. Winter 2007; Daniel Murray, 3 credit hours
21. Winter 2009; Anthony Mansoor, 3 credit hours
22. Winter 2009, Lucas Vanderpool, 3 credit hours

CONTIBUTIONS TO RESEARCH

Major Research Accomplishments

Dr. Assanis' research interests lie in the thermal sciences and their applications to energy conversion, power and propulsion, and automotive systems design. His research focuses on analytical and experimental studies of the thermal, fluid and chemical phenomena that occur in internal combustion engines, after-treatment systems, and fuel processors. His efforts to gain new understanding of the basic energy conversion processes have made significant impact in the development of energy and power systems with significantly improved fuel economy and dramatically reduced emissions. His group's research accomplishments have been published in over 250 articles in journals and international conference proceedings. More specifically:

- Over the past 25 years, he has made major contributions in modeling and computer simulation of internal combustion engine processes and systems, under steady-state and transient operation, and in carrying-out sophisticated in-situ experimental techniques, applicable to operating engine combustion chambers, to validate their fidelity. His innovative work has shed light into complex fuel-air mixing, combustion, pollutant formation and transient heat transfer phenomena in metal and ceramic-insulated engine combustion chambers. His simulation models and experimental insights are used by engine researchers and developers (e.g., General Motors, Caterpillar, Argonne, Lawrence Livermore and Sandia National Laboratories) to improve vehicle fuel economy while at the same time satisfying ultra-stringent emissions standards.
- His group has pioneered the integration of high fidelity engine models with driveline and vehicle models and used these comprehensive tools for realistic assessment and design optimization of conventional and hybrid powertrain systems. His engine-in-vehicle simulation methodologies have contributed significantly to the dual need-dual use heavy-duty industry/U.S. Army ground mobility mission through the development and optimization of advanced propulsion systems with 2-3 times higher fuel efficiency and ultra low smoke and particulate emissions.
- He has made lasting contributions to the fundamental understanding of the chemical and physical processes that govern the operation of HCCI engines and their exhaust after treatment systems. His revolutionary insights make possible to operate engines in ultra clean, low temperature combustion, fuel economical regimes that constitute a paradigm shift from the traditional, high temperature, pollutant forming engine combustion. His HCCI combustion strategies and patents have assisted industry to improve fuel economy of clean gasoline and diesel cars by 15%-20%, while virtually eliminating NOx and particulate emissions.
- Over the past 15 years, Dr. Assanis has led the efforts to revitalize the University of Michigan's automotive engineering activities and transformed the Walter E. Lay Automotive Laboratory into a beehive of research activity (see the URL link: http://me.engin.umich.edu/autolab/). He has initiated large-scale projects involving partnerships among academia, government and industry, led the fundraising efforts through writing major proposals, and directed the research activities. He has collaborated extensively with faculty members, research scientists and post-doctoral scholars from various Universities and disciplines. He has directed the research of more than 50 Ph.D. and more than 100 MS and M.Eng. graduate students. His group's research accomplishments have been published in over 250 articles in journals and international conference proceedings. His group's engine and powertrain system simulations are used in industry, academia and government.

Grants and Contracts

Dr. Assanis has been the project director, principal or co-principal investigator for more than $100M in grants and contracts funded by automotive industry (General Motors, Ford Motor Co., Chrysler LLC and DaimlerChrysler Corporation, Mitsubishi Motors Co., Honda Motor Co., Borg Warner, Ricardo), the heavy-duty truck industry (Detroit Diesel Corporation, Caterpillar, Inc., International, Cummins, Caterpillar, Yanmar Diesel Engine Co, Komatsu), the oil industry (ExxonMobil Corporation, Lubrizol, Amoco Oil, Chevron, Ethyl Corporation), the U.S. government (Department of Defense, Department of Energy, NASA, EPA, National Science Foundation) and National Laboratories (Sandia, Argonne).

He currently directs or co-directs the:

- Automotive Research Center, (ARC), a UM-led, eight-university, U.S. Army Center of Excellence founded in 1994 to advance the state-of-the-art modeling and simulation of military and civilian ground vehicles. The current third phase ($40M in funding, July 2004 – July 2010) emphasizes research into the design of vehicles propelled by next-generation powertrain systems for a variety of energy supply sources. The ARC is the most advanced university-based automotive research center in the country and has provided both educational opportunities and a unique cooperative partnership among the military, academia and the automotive industry. Current University partners include Clemson University, Oakland University, University of Alaska-Fairbanks, University of Iowa, Virginia Tech University, and Wayne State University. For additional information, refer to http://arc.engin.umich.edu/
- General Motors-University of Michigan Engine Systems Research Collaborative Research Laboratory (GM/UM ESR CRL). This successful research partnership between the two institutions, initiated in 1998 and currently in its third, five-year phase ($15M in total funding, 1998-2013) uses the special expertise of UM to conduct fundamental research into core competitive areas for GM in order to significantly improve fuel economy and dramatically reduce emissions of next generation engines. The CRL has also motivated the growth and strengthening of additional areas of excellence of importance to GM and commensurate with the scholarly expertise and intellectual pursuits of the University faculty. For additional information, refer to http://gmcrl-esr.engin.umich.edu/
- UM-led Multi-University Consortium on HCCI/ Low temperature Combustion (LTC) Engine Research, funded since 2001 by the Department of Energy (approx. $10M of funding to 3/31/09). This innovative research holds the promise of delivering high fuel economy with dramatically reduced emissions through a paradigm-shift approach compared to the traditional, high temperature, pollutant forming engine combustion in today's engines. University of Michigan partners include Stanford, MIT, and UC Berkeley. A proposal for the renewal of our consortium to explore high pressure lean burn combustion, with the potential to improve engine efficiency by 20-40% has just been submitted to DOE.

Other Current Grants at The University of Michigan

Advanced Powertrain Modeling, Borg Warner, 1/06-12/08, $300,000, Principal Investigator.

Collaborative Development of Clean Diesel Exhaust Aftertreatment System Through Modeling and Testing, Michigan Economic Development Corporation, 21st Century Jobs Fund, $1,650,000, 1/1/07-12/31/09, Principal Investigator (proposal selection process conducted by American Association for the Advancement of Science; 61 awards from 505 submitted proposals).

General Motors R&D Center, "Modeling and Experimental Study of Boosted HCCI Engine," 7/1/07-12/31/09, $1,400,000, Principal Investigator.

U.S. Environmental Protection Agency, “Integrated Hydraulic Hybrid Propulsion System and Advanced Components for Maximizing Fuel Efficiency and Emissions Benefits,” 4/2006-12/2008, $226,000, Co-Principal Investigator; PI: Z. Filipi.

Ford Motor Company, “Development of Diesel EGR Cooler Fouling Model,” Ford-UM Alliance, 9/1/07-8/31/09, $200,000, Principal Investigator.

Pending

Department of Energy, Office of Basic Sciences, “Energy Frontier Research Center Efficient and Clean Combustion of 21st Century Transportation Fuels: DOE EFRC ECCO-FUELS,” The University of Michigan in partnership with Massachusetts Institute of Technology, Stanford University, University of California-Berkeley, University of Illinois at Urbana-Champaign, DOE Lawrence Livermore National Laboratories, 4/1/09-3/31/14, $25,000,000, Principal Investigator and EFRC Director (decision expected April 2009). Department of Energy, Office for Energy Efficiency and Renewable Energy, “A University Consortium for Efficient and Clean High Pressure Lean Burn Engines,” The University of Michigan in partnership with Massachusetts Institute of Technology and University of California-Berkeley, 9/1/09-8/31/12, $3,750,000, Principal Investigator and Consortium Director.

Competed

National Science Foundation, “A Proposal for the Establishment of an Engineering Research Center for Carbon Neutral Vehicles (ERC-CNV)”, The University of Michigan in partnership with Massachusetts Institute of Technology, University of California-Berkeley, University of Illinois at Urbana-Champaign, Michigan State University, North Carolina A&T State University, 9/1/08-8/31/13, $18,500,000, Principal Investigator and ERC Director; invited among 34/143 pre-proposals to submit a full proposal, and reached site visit round of 8 finalists.

Past Grants

Automotive Research Center (ARC) of Excellence in Modeling and Simulation of Ground Vehicles, Department of Defense: Phase I: 9/94-7/98, $9,000,000, Co-Principal Investigator and *Deputy Director (1/96-7/98)*;Phase II: 7/98-6/04, $25,000,000, Co-Principal Investigator (7/98-9/02) and Principal Investigator (9/02-6/04); *Deputy Director (7/98 to 9/00) and Director (9/00-6/04).*

Experimental Investigation of Heat Rejection Characteristics of I-4 and V-6 Engine Designs, Ford Motor Co., 1/95 to 6/96, $142,000, Principal Investigator.

Prediction of Engine Heat Rejection, Ford University Research Program, 1995, $50,000 (unrestricted grant), Principal Investigator.

Direct Injection of Natural Gas: In Cylinder CFD Computations, DOE/NASA, 1/95 to 12/96, $214,506, Principal Investigator

Engine Heat Transfer and Engine/Fuels Interaction Technology, Chevron Oronite Technology Group, 5/95 to 4/99, $8,000, Principal Investigator

Engine Friction Studies with Boundary-Friction Reducing Additives, Mobil Technology Group and ExxonMobil Research and Engineering Company, 1/96-8/15/00, Total Funding $919,362, *($183,540, 1/96-6/96; $135,822, 6/96-5/97; $250,000, 1/97-12/97; $200,000, 1/98-12/98; $100,000, 1/99-6/99; $50,000, 1/00-8/00)*, Principal Investigator.

Experimental Investigation of Heat Rejection Characteristics of Diesel Engine Designs, Ford Motor Co., 6/96-6/97, $20,000, Principal Investigator.

Study of Unburned Hydrocaron Emissions Mechanisms, Ricardo, 1997, $90,000 (gift), Principal Investigator.

Direct Injection of Natural Gas: In Cylinder CFD Computations, SANDIA, 3/97-2/98, $25,000, Principal Investigator.

Fuel Economy and Power Benefits of Cetane-Improved Fuels in Heavy-Duty Diesel Engines, Ethyl, 1997, $20,000 (gift), Principal Investigator.

Investigation of Thermal and Strength Characteristics of Metal Matrix Composite Pistons for Heavy-Duty Diesel Engines, Focus Hope, 1997-98, $60,000, Principal Investigator.

Effect of Metal Matrix Composite Liners on Engine Friction and Wear, Inco Limited, 1997-99, $50,000 (gift), Principal Investigator.

Optimizing the Performance and Emissions of a Direct-Injection Spark-Ignition Engine Using Multi-Dimensional Modeling, Honda Initiative Grant Program, 8/1/97-7/31/98, $25,000, Principal Investigator.

General Motors/UM Collaborative Research Laboratory (formerly Satellite Research Laboratory), 5/98-12/31/02, $5,000,000, GMCRL Co-Principal Investigator and Director, Advanced Powertrain Systems Division.

Effect of Exhaust Valve Opening on Cold Start Hydrocarbon Emissions, Ford Motor Company, 6/98 to 12/01, Total Funding $380,000 *($230,000, 6/98-12/99; $150,000, 1/00–12/00)*, Principal Investigator.

Ricardo Single Cylinder Research Engines, Mobil Technology Company, 9/1/98, $230,000 (gift), Principal Investigator.

Optimizing the Performance and Emissions of Direct-Injection Compression-Ignition Engines Using Multi-Dimensional Modeling, EPA, 9/1/98-8/31/99, $40,000, Principal Investigator.

Diesel Spray Combustion Modeling, Yanmar Diesel Engine Company, Japan, 9/1/98, $27,000 (gift), Principal Investigator.

Using Chemical Kinetics to Simulate Engine Performance and Emissions, Caterpillar, Inc., 1/1/99-12/31/99, $40,000 (gift), Principal Investigator.

Mixture Preparation and Nitric Oxide Formation in a GDI Engine Studied by Combined Laser Diagnostics and Numerical Modeling DOE/Sandia National Laboratory, 4/1/1999-3 /31/2002, $383,505, Co-Principal Investigator.

Development of Pressure Reactive Piston Technology for Improved Efficiency and Low NOx Emissions in Spark-Ignition (SI) and Compression Ignition (CI) Engines, Ford Motor Company/DOE PNGV Program, 10/12/99-5/31/2003, $436,825, Principal Investigator.

In Cylinder Pressure Sensors Using Thin Film Shape Memory Alloys, Orbital Research, 6/00-8/31/02, $120,000, Principal Investigator.

Systems Approach for Demonstrating Very Low Nox Emissions from a Direct-Injection Compression-Ignition (CIDI) Engine with a NOx Catalyst, EPA, 1/01-6/30/02, $100,000, Principal Investigator.

Concurrent Design of Next Generation Powertrains, Manufacturing Processes and Materials: A Simulation-Based Approach, US ARMY/TACOM under the Dual Use Science and Technology program DUST 2000, 4/3/01-4/2/03, $3,000,000, Co-Principal Investigator.

Simulation-Based Design and Demonstration of Next Generation Advanced Diesel Technology, Ford Motor Company/US ARMY TACOM under the Dual Use Science and Technology program DUST 2001, $2,420,000, 9/1/01 to 12/31/03, Principal Investigator.

A University Consortium on Homogeneous Charge Compression Ignition, Low Temperature Combustion for High Efficiency, Ultra-Low Emission Engines, The University of Michigan in partnership with Massachusetts Institute of Technology, Stanford University, and University of California-Berkeley, Department of Energy, Phase I: 10/1/01-3/31/06, $4,800,000, Principal Investigator and Consortium Director.

General Motors/UM Collaborative Research Laboratory on Engine Systems Research, “Advanced Diesel Combustion System Optimization Tools Implementation,” 6/1/04-8/31/04, $17,160, Principal Investigator and GMCRL Co-Director.

General Motors/UM Collaborative Research Laboratory on Engine Systems Research, “Advanced Diesel Combustion System Development and Measurement of Hydrocarbon Species and Unregulated Emissions from Diesel Engines Operating in Advanced Combustion Modes,” 9/1/03-8/31/04, $116,206, Principal Investigator and GMCRL Co-Director.

General Motors/UM Collaborative Research Laboratory on Engine Systems Research, “Experimental Assessment of Design Concepts for Robust Spray-Guided Stratified-Charge Combustion,” 8/1/04-7/31/05, $135,168, Principal Investigator and GMCRL Co-Director.

Precision Heat Management in SI Engines, DaimlerChrysler Challenge Fund Project, $180,000, 9/1/01 to 12/31/04.

Detailed Exhaust Hydrocarbon Measurements in a Multi-Cylinder Engine, Ford Motor Company, 9/1/03 to 8/31/05, $98,000, Principal Investigator.

Engine-In-Vehicle Modeling, Navistar, 1/1/99-12/06, $300,000, unrestricted grant, Co-Principal Investigator.

General Motors/UM Collaborative Research Laboratory on Engine Systems Research, “PCCI Diesel Engine Combustion and Aftertreatment Systems,” 9/19/2006, $85,000, unrestricted grant, Principal Investigator.

Fuel Processors for PEM Fuel Cells, Department of Energy, 10/01-9/06, $4,545,471, Co-Principal Investigator.

Eaton Corporation Innovation Center, “Assessment of the NOx Reducing Potential of NOx Adsorber-NH3 SCR Exhaust Aftertreatment Systems,” Phase I: 7/1/04 to 6/30/05, $114,876; Phase II: 7/1/05-12/31/06, $60,000, Principal Investigator.

General Motors/UM Collaborative Research Laboratory on Engine Systems Research, “Discovery Project: Free Piston Linear Alternator,” 6/1/05-8/31/07, $528,245, Principal Investigator.

Investigation of VVT Fuel Economy and Emissions Benefits under Cold-Start, Idle and Low Load Conditions, DaimlerChrysler Challenge Fund Project, 1/1/05 to 6/30/08, $300,000, Principal Investigator.

Grants and Contracts at University of Illinois in Urbana-Champaign

Effect of Combustion Chamber Insulation on Turbocharged Diesel Engine Performance, UIUC-Research Board, 3/20/86 - 6/30/87, $20,000 (grant), Principal Investigator

Intake Valve Event Optimization for Specified Engine Operating Conditions, General Motors Pontiac Group, 8/21/86 to 6/30/88, $31,000, Co-Principal Investigators: J. E. Peters and D.N. Assanis, Project Director: D.N. Assanis

Development of a Modern Engine Test Cell for Studies of Low-Heat-Rejection Engine Performance, UIUC-Research Board, $6,000 (grant), 1/15/87 to 1/15/88, Principal Investigator

NSF, An Experimental and Analytical Study of Unsteady Heat Transfer in Low-Heat-Rejection Engine Combustion Chambers, $69,983, 7/1/87 to 11/30/89, Principal Investigator

Development of an Integrated Rankine Bottoming Cycle for Diesel Engine Exhaust Heat Recovery, UIUC-Research Board, $7,624 (grant), 8/21/87 to 5/21/88, Principal Investigator

Adiabatics, Inc., Development and Use of a Computer Simulation Code for LHR Vehicle Fuel Economy, $30,926, 9/1/87 to 7/31/88, Co-Principal Investigators: D. N. Assanis, R. A. White, Project Director: D.N. Assanis

Analysis and Testing of Ceramic-Coated Engine Components, Adiabatics, Inc., $14,466, 9/1/87 to 12/31/88, Principal Investigator

Fluidized Bed Heat Recovery from Diesel Engines, U.S. Army CERL, $13,692, 9/15/87 - 5/31/88, Principal Investigator

Engineering Research Equipment Grant: A Modern Single-Cylinder Engine Test Facility for Diesel Engine Research, NSF, $51,400 (equipment grant), from 5/1/88 to 10/31/89, Principal Investigator

Presidential Young Investigator Award: Engine Combustion and Emissions Studies, NSF, $312,500, 6/88 to 12/93, Principal Investigator

A Modern Single Cylinder Diesel Research Engine, Caterpillar, $27,000 (gift), 7/7/88, Principal Investigator

Development of Multi-Dimensional Heat Transfer Models for LHR Engine Studies, National Center for Supercomputing Applications, 35 CPU hours on CRAY X/MP, 3/88 to 12/89, Principal Investigator

Combustion and Emissions of Low-Heat-Rejection Diesel Engines, $129,223, U.S. Army TACOM, 8/88 to 8/90, Principal Investigator

The Effect of Light Weight Reciprocating Components on Engine Combustion, Frictional Losses, and Heat Transfer, Chrysler, 8/88 - 8/90, $115,992, Principal Investigator

An Optical Table for Laser Velocimetry, $6,311 (gift), Newport Corp., from 4/89, Principal Investigator

Support for Women, Minorities, and Disabled Engineering Research Assistants, NSF, 2/89 - 2/90, $4,958, Principal Investigator

Development of an Improved Combustion Model for Use in a Multi-dimensional Engine Simulation, National Center for Supercomputing Applications, 90 CPU hours on CRAY X/MP and CRAY 2, 12/89 - 12/90, Principal Investigator

An Experimental and Analytical Study of Unsteady Heat Transfer in LHR Engines - REU Supplement, NSF, 2/1/90 to 7/31/90, $8,973, Principal Investigator

Investigation of a Fluidized Bed Heat Exchanger, U.S. Army CERL, 8/90 to 5/91, $16,935, Principal Investigator

Development of a Hydrocarbon Emissions Model for Multi-Dimensional Engine Simulation, National Center for Supercomputing Applications, 80 CPU hours on CRAY X/MP and CRAY 2, 4/90 - 4/91, Principal Investigator

Effect of Reed Valves in the Intake Ports on SI Engine Performance and Knock, Ford Motor Company, 8/21/90 to 12/93, $169,377, Co-Principal Investigators: D.N. Assanis, J. E. Peters, R. A. White, Director: D. N. Assanis

A Study of Fuel-Air Distribution in the Intake System of a Spark-Ignited Natural Gas Engine, Cummins, 8/21/90 - 5/31/94, $140,000 (gift), Co-Principal Investigators: D. N. Assanis, R. A. White

Lignin-Augmented Bituminous Coal Depolymerization: A Route to Clean Fuels, Center for Research on Sulfur in Coal, $105,036, Co-PI, 8/21/90 to 8/31/91, Co-Principal Investigators: D. N. Assanis, C. Kruse, PD: C. Kruse

Prediction of 3-D Turbulent Flows Using a BFC Computer Code, National Center for Supercomputing Applications, $24,000 and 50 CPU hours on CRAY 2, 9/90 - 8/92, Principal Investigator

Joint Research Program between Mitsubishi Motors Corp. and University of Illinois, Mitsubishi Motors Corp., $340,000 6/1/91 to 5/31/93, Co-Principal Investigators: D. N. Assanis, R. A. White, H. Sehitoglu, D. Socie, Project Director: D. N. Assanis

Octane Requirement Increase and its Relation to Combustion Chamber Deposits, Amoco Oil Company, $130,798, 9/1/91to 12/93, Co-Principal Investigators: D. N. Assanis, R. A. White, Project Director: R. A. White

Integrated Production/Use of Ultra Low Ash Coal, Center for Research on Sulfur in Coal, $148,959, Co-PI, 8/91- 8/92, Co-Principal Investigators: D. N. Assanis, C. Kruse, Project Director: C. Kruse

Development, Optimization, and Testing of a 3-D Computational Fluid Dynamics Code, National Center for Supercomputing Applications, 96 hours on CRAY Y-MP, 11/91 to 12/92, Principal Investigator

A Modern Set of Emissions Analyzers for Internal Combustion Engine Pollution Studies, UIUC Research Board, $42,000 (grant), 10/91, PI

Development of a Comprehensive Evaporation Model for Use in a Multi-Dimensional Engine Simulation, National Center for Supercomputing Applications, 85 CPU hours on CRAY X/MP and CRAY 2, 11/92 - 12/93, Principal Investigator

Effects of Combustion Characteristics on Heat Loss under Knocking and Non-Knocking Conditions, Mitsubishi Motor Company, 6/93 - 5/95, $200,085, Co-Principal Investigator: D. N. Assanis

An Improved Model for Droplet Evaporation in High Pressure Diesel Sprays, UIUC Research Board, $6,728 (grant), 6/93 to 12/93, Principal Investigator

Design of Low Distortion Insulated Piston/Liner System, Inco Ltd., $25,000 (gift), from 8/93 - 8/95, Principal Investigator

RISC-6000 Workstations for Computation and Visualization of Reactive Engine Flows, IBM, $39,888 (gift), from 12/93, Co-Principal Investigators: D. N. Assanis, R. A. White

Direct Injection of Natural Gas: In Cylinder CFD Computations, DOE/NASA, 1/94 to 12/94, $231,174, Co-Principal Investigators: D. N. Assanis, J. E. Peters, R. L. Lucht, Project Director: D.N. Assanis

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10. Assanis, D. N., "3-D Modeling of Engine Reacting Flows: Promises and Challenges," invited paper, Panel on Automotive Applications of CFD, Atlanta, 1996 ASME International Mechanical Engineering Congress and Exposition, Atlanta, GA, Nov. 17-22, 1996.
11. Papageorgakis, G., and D. N. Assanis, "Implementation and Assessment of Alternative Turbulence Models in KIVA-3," Seventh International KIVA Users Group Meeting, Detroit, MI, Feb. 25, 1996.
12. Assanis, D. N., "Engine Friction Measurements," invited presentation, Panel on Surface Engineering and Tribology, SAE International Congress and Exposition, Detroit, MI, Feb. 23-26, 1998.
13. Assanis, D. N., "Engine Friction Measurements," Keynote Presentation, DOE Workshop on Research Needs for Reducing Friction and Wear in Transportation, Argonne National Laboratory, March 22-23, 1999.
14. Assanis, D.N., Louca, L., and Z. Filipi, "Drivetrain Simulation and Modeling Based Upshift Control," Modern Advances in Automatic Transmission Technology TPOTEC, Ypsilanti, MI, Aug. 29-30, 2002.
15. Assanis, D. N. and S. Tung, "Overview of Engine Friction and Wear Measurements," Future Trends in Engine Design and Tribology, Society of Tribologists and Lubrication Engineers, Rochester, MI, August 22, 2001.
16. Assanis, D. N., "Modeling of Hybrid Vehicle Systems", invited presentation, 7th International Conference on Present and Future Engines for Automobiles, Delphi, Greece, May 27-31, 2001.
17. Assanis, D. N., "Discussion of the National Research Council Report on Corporate Average Fuel Economy," SAE President's Invited Panel, 2002 SAE International Congress and Exhibition, 2002 SAE World Congress, Detroit, MI, March 4-7, 2002.
18. Fiveland, S. and D. N. Assanis, "A Quasi-Dimensional HCCI Model for Performance and Emissions Studies," Ninth International Conference on Numerical Combustion, Sorrento, Italy, April 7-10, 2002.
19. Assanis, D. N., "Does the Internal Combustion Engine Have a Future?", The Advanced Power Technology Forum, Management Briefing Seminars 2002, Traverse City, MI, August 5-9, 2002.

20. Assanis D. N., “Does the Internal Combustion Engine Have a Future?”, invited plenary speaker, session on “Future Automotive Powertrains,” Global Powertrain Congress, Ann Arbor, MI, September 24-26, 2002.
21. Assanis, D.N., “Securing a Successful Academic Career,” invited panelist, ASME IMECE, New Orleans, LA, November 17-22, 2002.
22. Filipi, Z. S., Wu, B., Lin, C.C., and D. N. Assanis, “Fuel Economy Potential of Hydraulic Hybrid Propulsion Systems for Medium Trucks,” SAE International Truck and Bus Meeting and Exhibition, Cobo Center, Detroit, MI, November 18-20, 2002.
23. Assanis, D.N., “A University Consortium on Homogeneous Charge Compression Ignition Engine Research,” invited speaker, International Workshop on Advanced Combustion and Fuels,” Argonne National Laboratory, Argonne, IL, June 16-17, 2003.
24. Assanis, D.N., “Major Research Issues,” invited panelist, International Workshop on Advanced Combustion and Fuels,” Argonne National Laboratory, Argonne, IL, June 16-17, 2003.
25. Vanzieleghem, B.P., Chryssakis, C.A., Grover, R.O., Assanis, D.N., Im, H.G., and V. Sick, “Gasoline Direct Injection Modeling and Validation with Engine Planar Laser Induced Fluorescence Experiments,” 14th International Multidimensional Engine Modeling User’s Group Meeting, Detroit, MI, March 2004.
26. Depcik, C., and D.N. Assanis, “One-Dimensional Catalyst Modeling and its Application to Urea SCR Devices,” Seventh CLEERS Workshop, Detroit Diesel, Detroit, MI, June 2004.
27. Assanis, D.N., et al., “Clean and Controllable, Advanced Compression Ignition Engine System for Improved Power Density and Fuel Economy”, plenary session presentation at the Annual ARC Conference on “Critical Technologies for Modeling and Simulation of Ground Vehicles”, Ann Arbor, May 2004.
28. Babajimopoulos, A., Assanis, D.N., Flowers, D.L., Aceves, S.M., and R.P. Hessel, “A Fully Integrated CFD and Multi-Zone Model with Detailed Chemical Kinetics for the Simulation of PCCI Engines,” 15th International Multidimensional Engine Modeling User’s Group Meeting, Detroit, MI, April 2005.
29. Assanis, et al., “Engine-In-the-Loop Simulation: A Design and Evaluation Tool for Advanced Propulsion Systems”, plenary session presentation at the Annual ARC Conference on “Critical Technologies for Modeling and Simulation of Ground Vehicles”, Ann Arbor, May 2005.
30. Assanis, D. N., “Bridging the Gap between Fundamental Physics and Chemistry and Applied Models for HCCI Engines”, invited presentation, 9th International Conference on Present and Future Engines for Automobiles, San Antonio, TX, May 29 to June 2, 2005.
31. Assanis, D. N., “Bridging the Gap between Fundamental Physics and Chemistry and Applied Models for HCCI Engines”, invited presentation, 11th International Conference on Diesel Engine Emissions Reduction DEER 2005, Chicago, IL, August 21-25, 2005.
32. Leustek, M.E., Sethu, C., Bohac, S., Filipi, Z., and D.N. Assanis, “Crank-angle Resolved In-Cylinder Friction Measurements with the Instantaneous IMEP Method”, Proceedings of World Tribology Congress III, Washington D.C., Sept. 2005.
33. Assanis, D.N., et al., “Integrative Approach to Advanced Propulsion System Design Using Simulation and Engine-In-the-Loop”, plenary session presentation at the Annual ARC Conference on “Critical Technologies for Modeling and Simulation of Ground Vehicles”, Ann Arbor, May 2006.
34. Assanis, D. N., “Low Temperature Combustion for High Efficiency Ultra Low Emissions Engines”, invited presentation, 12th International Conference on Diesel Engine Efficiency and Emissions Reduction DEER 2006, Detroit, MI, August 20-24, 2006.

35. Assanis, D. N., “Analysis and Control of HCCI Engine Transient Operation Using 1-D Cycle Simulation and Thermal Networks”, invited presentation, SAE HCCI Engine Symposium, San Ramon, CA, September 24-26, 2006.
36. Assanis, D. N., “Next Generation Powertrains and Fuels: Grand Challenges and Opportunities”, invited presentation, UM Symposium on Energy Science, Technology and Policy, Ann Arbor, MI, February 13-14, 2007.
37. Assanis, D.N., “Energy Research: Grand Challenges and Opportunities,” invited talk, Lehigh University, Bethlehem, PA, February 2, 2007.
38. Assanis, D.N., “Today’s Students, Tomorrow’s Engineers,” Invited Panelist, SAE 2007 World Congress, Detroit, MI, April 16-19, 2007.
39. Assanis, D.N., et al, “Energy and Power for Military Vehicles: Alternative Fuels and Hybrid Propulsion”, plenary session presentation at the Annual ARC Conference on “Critical Technologies for Modeling and Simulation of Ground Vehicles”, Ann Arbor, May 2007.
40. Assanis, D. N., “On Modeling HCCI Engine Transient Behavior”, invited presentation, 10th International Conference on Present and Future Engines for Automobiles, Rhodes, Greece, May 28 to June 5, 2007.
41. Assanis, D.N., “TechKnow: Alternative Fuel Cars,” Invited Panelist, June 12, Power Center, Ann Arbor, MI.
42. Assanis, D.N., “Analysis and Control of HCCI Engine Transient Operation”, invited presentation, Homogeneous Charge Compression Ignition (HCCI) Symposium, Lund, Sweden, September 12-14, 2007.
43. Assanis. D.N., “Low Temperature Combustion for High Efficiency, Ultra-Low Emission Engines” invited talk, University of Illinois at Urbana-Champaign, April 1, 2008.
44. Middleton, R. and D. N. Assanis, “Nitrogen Oxides Oxidation as a Function of Lean NO Trap Loading,” 11th DOE Crosscut Workshop on Lean Emissions Reduction Simulation, University of Michigan - Dearborn, May 13th - 15th, 2008.

<u>Books Edited</u>

Uzkan, T., and Assanis, D. N., Editors, “Advanced Engine Simulations, Volume 1, *Proceedings of the 1997 ASME-ICE Spring Technical Conference*, ICE-Vol. 28-1, ASME, 1997.

Assanis, D.N., Papalambros, P.Y., and Bryzik, W., Guest Editors, Haug, E., Editor, Automotive Research Center Special Edition Issue, *Mechanics of Structures and Machines*, 27:4, 1999.

Zhao, F., Asmus. T., Assanis, D. N., Dec. J. E., Eng, J. A., and P. M. Najt, *Homogeneous Charge Compression Ignition (HCCI) Engines: Key Research and Development Issues*, SAE PT-94, Society of Automotive Engineers, Warrendale, PA, 2003.

Assanis, D.N., Bryzik, W., Gorsich. D., and Haque, I., Guest Editors, Automotive Research Center Special Edition Issue, *International Journal of Heavy Vehicle Systems*, 11:3/4, 372-402, 2004.

Cheng, W.K., Dibble, R., and D.N. Assanis, Guest Editors, *International Journal of Engine Research*, Special Issue on HCCI Engines, 6:5, 2005.

<u>Chapters in Books</u>

Assanis, D.N., Cole, D., Jacobs, T.J., and D.J. Patterson, "Internal Combustion Engines," *Marks’ Standard Handbook for Mechanical Engineers*, pp. 9-93 to 9-127, 11th Edition, McGraw-Hill Book Company, 2007.

Assanis, D.N., Borgnakke, C., Patterson, D.J., and Cole, D., "Internal Combustion Engines," *Marks' Standard Handbook for Mechanical Engineers*, pp. 9-90 to 9-121, 10th Edition, McGraw-Hill Book Company, 1996.

Assanis, D.N., Lavoie, G. A. and S. B. Fiveland, "HCCI Engine Modeling Approaches," pp. 529-655, published in *Homogeneous Charge Compression Ignition (HCCI) Engines: Key Research and Development Issues*, SAE PT-94, Society of Automotive Engineers, Warrendale, PA, 2003.

<u>Inventions and Patents</u>

Church, C., Smith, F., and D.N. Assanis, "Use of Singlet Delta Oxygen to Enhance the Performance of Internal Combustion Engines, Diesel Engines in Particular," Patent No. 6,659,088, granted 12/9/2003.

Wu, B., Filipi, Z., Assanis, D.N., Kramer, D., Ohl, G., Prucka, M., and E. DiValentin, "Artificial Neural Networks for Estimating the Air Flow Rate through a VVT Engine", Invention Development Record P706964 disclosed 04/21/2004. Filed by a joint team of UM and DCX researchers.

Shih, A.J., Filipi, Z., and D.N. Assanis, "Pre-Turbocharging Catalyzed Porous Metal Foam Filter for Diesel Particulates Treatment", Invention Disclosure No. 2924 to UM Tech Transfer Office, July 2004.

Najt, P.M., Eng, J.A., Chang, J., Filipi, Z.S., Guralp, O., and D.N. Assanis, "Method for Mid-Load Operation of Auto-Ignition Combustion," Patent No. 7,128,062 B2, granted 10/31/2006.

Kuo, T.W., Najt, P., Eng, J.A., Rask, R.B., Guralp, O., Hoffman, M., Filipi, Z.S., and D.N. Assanis, "Method and Apparatus to Determine Magnitude of Combustion Chamber Deposits," Patent No. 7,367,319, granted 12/31/2007.

Laurie A. Harbour-Felax
15625 Amherst
Beverly Hills, MI 48025
Home: 248-792-6792
Cell: 248-875-7833

Professional Experience

Harbour-Felax Group – Troy, MI — President
September 2005 to Present

Harbour Consulting – Troy, MI — Vice President, Partner
January 1988 to September 2005

Business Development

- Responsible for business development: sales and marketing, presentations, generation of leads, management of sales plan, meetings with clients (presidents, vice presidents and their staffs), proposal generation and follow up.
- Regularly present and attend key automotive events for business development and networking (OESA, APMA, Traverse City, Greenbrier, SAE, Autotech, SAA, etc.).
- Leverage contacts to schedule initial meetings to present services.
- Work with marketing firm to re-brand Harbour and create new marketing materials and messaging for potential clients.
- Manage relationships with strategic partners to grow business for both firms.
- Major contributor to revenue growth of 63% from 2002 to 2004 and 25% for 2005.
- Responsible for Harbour's diversification strategy into defense and military.
- Created the original concept of the annual Harbour Report in 1991; developed the business plan to take the report global and executed this plan over the last 10 years; Europe launched in 1996; Asia planned for 2006; South America planned for 2007.
- Assist in growth of *The Harbour Report* from $150K in 1994 to $1.8 million in 2005.

Operations Management

- Responsible for resource planning of projects: assign project leaders and staff projects with appropriate skill set and support resources.
- Involved in search of new employees, interviewing and hiring of staff.
- Attend project reviews; provide guidance and direction to resolve issues with projects.
- Act as a project champion and accountable for success of majority of projects.
- Partial responsibility for decisions on major purchases and deviations from the budget.
- Conduct training and orientation for all employees on Harbour history, strategic plan, policy deployment and the state of the auto industry.
- Coaching, mentoring.
- Day-to-day responsibility for management of 24-person office in Troy; 3-person office in Bangkok.
- Responsible for management of a 27-person team with seven direct reports.
- Directly report to the President.
- Trustee of retirement plan.

Strategic Planning

- Work with partner to establish strategic vision and direction for the company.
- Responsible for development and maintenance of the 5, 3 and 1-year business plan.
- Develop annual policy deployment: objectives, improvement plans, team priorities, and scorecard development.
- Creation, approval and management of the annual budget.
- Maintenance of the business plan: weekly business planning meetings and monthly scorecard and policy deployment reviews.
- Initiate course corrections to the business plan through the year.
- Work with clients to develop strategic plans and future vision, bringing industry knowledge of the competition and opportunities.

Project Management

- Project leader of the North American and European *Harbour Reports* until 1998: business development, data analysis, plants visits, text management and presenting to client.
- Since 1998 high-level oversight of *The Harbour Report* including issue resolution, high-level client meetings, development of text, text editing, etc.
- Developed a continuous improvement process to receive input from the participants and customers of *The Harbour Report*.
- Led the development and implementation of a web database to manage *The Harbour Report*.
- Led numerous benchmarking and manufacturing projects for OEM's and suppliers worldwide.
- Trained over 2000 people at a major OEM: state of the auto industry, hours per vehicle, how product and process engineering work with manufacturing.
- Currently training OEM union level teams of how to achieve competitiveness.
- Currently training OEM union level teams in lean manufacturing principals: competitiveness, 7 wastes, 5's, standardized work, etc.

Manufacturing Experience

- Visit over 30 auto plants worldwide (domestic, Japan, Korea, China, etc.) each year in conjunction with *The Harbour Report* and assist in plant reviews with staff and senior level executives.
- Visit several other manufacturing plants in conjunction with consulting projects and assist in consulting projects from a champion role.
- Accumulated a significant database of best practices through years of plants visits.
- Specific manufacturing experience in stamping, body, paint, trim, chassis, final, machining and powertrain assembly.
- Thorough understanding of World Class production system techniques and have assessed and been trained in the Toyota Production System, GMS, Ford Production System and other company's operating philosophies.

Additional Skills

- Excellent verbal and written communication skills.
- Interface with all levels of organizations: CEO's, presidents, senior level executives, plant managers, union officials and shop floor workers.
- Work extensively with union leaders to understand their role and need for competitiveness.
- Regularly speak in public events (18 key notes in 2005 to date).

- Regularly quoted in media, newspaper and radio as an auto analyst.
- Strong leadership skills.

Education and Trainings

- Bachelor's degree in Operations Management and Human Resources, University of Michigan
- Empowerment Leadership Training – 1987, 1988, 1999 – Farmington Hills, MI
- LifePlan Leadership Training – 2002 – Rochester, MI
- Individual Leadership Training – 2003, 2004 – Troy, MI
- Lean Experience – 2005 – Lean Learning Center, Novi, MI
- SMART Training – 2005 – DaimlerChrysler Lean Training, Warren, MI

VITA

Sujit Das

Oak Ridge National Laboratory	(865) 946-1222
National Transportation Research Center	FAX: (865) 946-1314
2360 Cherahala Blvd.	Email: Dass@ornl.gov
Knoxville, Tennessee 37932-6472	

EDUCATION

MBA	Management Science and Computer Science, University of Tennessee 1984
MS	Metallurgical Engineering, University of Tennessee, 1982
B. Tech	Metallurgical Engineering, Indian Institute of Technology, Kharagpur, India, 1979. Ranked IInd in class with Honors.

PROFESSIONAL EXPERIENCE

Sr. Research Staff Member, Energy and Transportation Science Division, Oak Ridge National Laboratory, December 1984-present.

Program manager of the cost modeling of lightweight materials and biomass energy analysis programs for the U.S. Department of Energy. Develop, manage and lead projects for the DOE Office of FreedomCAR and Vehicle Technologies. Responsible for a total annual budget of more than $750K consistently over the past several years. Develop cost models of advanced materials and transportation technologies and decision-making tools for several resource markets. Provide market assessments of energy efficient technologies including environmental implications for both domestic and international markets. Developed expertise in several multi-disciplinary research areas including:

- Market potential and infrastructure assessment of ethanol and hydrogen as alternative transportation fuels
- Cost modeling and life cycle analysis of advanced vehicles and lightweight materials technologies
- Material technology assessments related to Partnership for A New Generation of Vehicles (PNGV)/Freedom Cooperative Automotive Research (FreedomCAR)
- Biomass refinery analysis
- Economic analysis of advanced power electronics, electric motors, and intelligent transportation systems
- Energy efficiency of distribution transformers
- Cost of alternative fuels
    - Forecasting of petroleum and uranium supplies
- Estimation of flood-stage economic damages
- The economic viability of plastics and automobile recycling
- Environmental implications of privatization of the power sector in India
- Market assessments of energy efficient technologies such as home refrigerators in India
    - Inspection and Maintenance of two-wheeler vehicles in India
    - Assessment of uranium resources

Visiting Fellow, Tata Energy Research Institute (TERI), New Delhi, India, October 1992-June 1993.

Developed a comprehensive, computerized, and PC-based Energy-Economic-Environment database for TERI -- the first of its kind in India and provided technical support in their ongoing energy and economic modeling activities.

Research Assistant, Energy and Economic Analysis Section, Oak Ridge National Laboratory, September 1982-December 1984.

Documented and evaluated several EIA, DOE maintained computers models, i.e., Headwater Benefit Energy Gains Model and the Petroleum Allocation Model. Developed a computer software "BIOCUT" for Economic Evaluation Model for Wood Energy Plantations.

LIST OF PUBLICATIONS

BOOK PUBLISHED

"Material Use in Automobiles." A Book Chapter in Encyclopedia of Energy, published by Elsevier Inc., Vol. 3, pp. 859-869, 2004.

"Plastic Wastes: Management, Control, Recycling, and Disposal." Noyes Data Corporation, NJ (Co-Authored with U.S. Environmental Protection Agency and T. R. Curlee), 1991.

SELECTED REFERRED ARTICLES (Out of 50+ articles)

"Primary Magnesium Production Costs for Automotive Applications," Journal of Metals, Vol. 60, No. 11, 2008, pp. 51-58.

"A Systems Approach to Life Cycle Truck Cost Estimation," SAE Paper No. 2006-01-3562, Society of Automotive Engineers, Warrendale, PA.

"Automotive Lightweighting Materials Benefit Evaluation," ORNL/TM-2006/545, Oak Ridge National Laboratory, Oak Ridge, TN, Nov. 2006

"Lightweight Opportunities for Fuel Cell Vehicles," SAE Paper No. 2005-01-0007, Society of Automotive Engineers, Warrendale, PA.

"A Comparative Assessment of Alternative Powertrains and Body-in-White Materials for Advanced Technology Vehicles," SAE Paper No. 2004-01-0573, Society of Automotive Engineers, Warrendale, PA.

"Back To Basics? The Viability of Recycling Plastics by Tertiary Approaches," Working Paper #5, Program on Solid Waste Policy, School of Forestry and Environmental Studies, Yale University, New Haven, CT, September 1996. (with T. R. Curlee)

"Determination Analysis of Energy Conservation Standards for Distribution Transformers. ORNL-6847, Oak Ridge National Laboratory, Oak Ridge, TN, July 1996.

Wallace R. Wade, P.E.
50786 Drakes Bay Dr.
Novi, MI 48374
Phone: 248-449-4549
email: wrwade1@gmail.com
DOB: August 6, 1941

1. Academic Background

MSME	University of Michigan, Ann Arbor	1964	Mechanical Engineering
BME	Rensselaer Polytechnic Institute	1963	Mechanical Engineering

2. Professional Licenses/Certification

Registered Professional Engineer, State of Michigan

3. Relevant Professional Experience

Areas of Expertise:
- Engine research and development
- Emission control systems
- Powertrain electronic control systems
- Powertrain calibration
- Systems engineering

1994 – 2004	Chief Engineer and Technical Fellow
(Retired Oct 2004)	Powertrain Systems Technology and Processes
(32+ years service)	Ford Motor Company, Dearborn, MI

Responsible for development, application and certification of emission and powertrain control system technologies for all Ford Motor Company's North American vehicles.
- Developed technologies for emission control systems, powertrain control systems, OBD II (On-Board Diagnostic) systems and powertrain calibration procedures. Achieved U.S. EPA (Environmental Protection Agency) and CARB (California Air Resources Board) certifications for all 1993-2005 model year North American vehicles.
  - Developed and implemented, in production, new technology catalyst systems for increasingly stringent emission standards with significant reductions in precious metal usage.
  - Developed technologies for California LEV II (Low Emission Vehicle – 2nd Generation) and EPA SFTP (Supplemental Federal Test Procedure) regulations.
- Developed key low emission technologies for the engine, powertrain control system, exhaust emission and vapor emission control systems in the 2003 California SULEV (Super Ultra Low Emission Vehicle) Ford Focus, which was the first domestic production vehicle complying with the most stringent emission levels required by the California Air Resources Board.
- Developed the first analytical and laboratory based (engine and vehicle) automated powertrain calibration process with objective measures of driveability to replace the traditional on-the-road calibration process resulting in significant reductions in test vehicles and significant improvements in efficiency.

- Initiated production implementation of the first domestic application of a diesel particulate filter (DPF) with active regeneration.

Co-Chairman of the Ford Corporate Technical Specialist Committee which provided corporate overview in promoting deep technical expertise through the selection and appointment of technical specialists.

1992-1994 Assistant Chief Engineer
Powertrain Systems Engineering
Ford Motor Company, Dearborn, MI

Responsible for the development and certification of emission and powertrain control systems for all Ford Motor Company's North American vehicles.

  - Developed and implemented, in production, the California LEV (Low Emission Vehicle) requirements featuring palladium-only catalysts and coordinated strategy for starting with reduced emissions (CSSRE).
- Developed and implemented OBD II, which was phased-in on all North American vehicles over the 1994-1996 model years.
  - Developed and phased in the advanced EEC V electronic engine control system on all production vehicles over the 1994-1996 model years.
  - Led the development and implementation of enhanced evaporative emission and running loss controls that were phased-in over the 1995-1999 model years.
  - Led the establishment of systems engineering in the development of powertrain systems. Design specifications were developed for all powertrain sub-systems.

1990-1992 Executive Engineer/Manager
Powertrain Electronics (Containing 4 Departments)
Ford Motor Company, Dearborn, MI

Responsible for the development and production implementation of powertrain electronic control systems (hardware and software) for all of Ford Motor Company's North American vehicles.

- Developed production powertrain electronic control systems for all North American vehicles.
- Developed the technology for OBD II and the advanced EEC V electronic engine control system.
- Led the Powertrain Electronics Control Cooperation (PECC) program resulting in the application of Ford EEC V systems on 30% of Mazda vehicle lines by the 2000 model year.
  - Initiated the development of Ford's next generation 32-bit powertrain electronic control system (PTEC) (implemented in the 1999 model year).

1987-1990 Manager
Advanced Powertrain Control Systems Department
Ford Motor Company, Dearborn, MI

Responsible for the development of powertrain control system technology for future applications.

- Developed the first Ford California ULEV (Ultra Low Emission Vehicle) emission control system. Major improvements in air/fuel ratio control were achieved using a UEGO (universal exhaust gas oxygen) sensor and a proportional control algorithm.

- Developed enhanced evaporative and running loss emission control concepts.
- Developed the first Ford traction control system using engine torque modulation combined with brake modulation.
- Developed the first Ford electronic throttle control (drive-by-wire) system for improved driveability (implemented in production for the 2003 model year).
- Developed engine torque modulation during shifting for imperceptible automatic transmission shifts.
- Initiated the requirements specification for a new 32-bit powertrain electronic control system (PTEC).

1978-1987 Manager
Engine Research Department
Research Staff
Ford Motor Company, Dearborn, MI

Responsible for the creation, identification and feasibility prove-out of advanced engine concepts for next generation vehicle applications.
- Developed the first Ford passenger car, direct-injection diesel that met current emission requirements and provided 10-15% fuel economy improvement vs. indirect injection diesel.
- Developed light-duty diesel electronic control systems that achieved significant reductions in emissions.
- Developed the first Ford adiabatic diesel engine with a ringless ceramic piston operating in a ceramic cylinder.
- Developed the concept and demonstrated the first Ford diesel particulate filter (DPF) with active regeneration that provided over 90% reduction in particulate emissions (scheduled for production in a Ford vehicle in 2007).

1974-1978 Supervisor, Development Section
Diesel Engine and Stratified Charge Engine Department
Ford Motor Company

Responsible for the research and development of low emission, fuel-efficient stratified charge engines (PROCO stratified charge, 3 valve CVCC (Compound Vortex Controlled Combustion), spark ignited-direct injection) and diesel engines.

1972-1974 Supervisor/Senior Research Engineer
Turbine Controls and Combustion Section
Ford Motor Company

Responsible for the research and development of low emission combustion systems for a high temperature, ceramic gas turbine engine.
- Developed the first successful premixed, pre-vaporized, variable geometry gas turbine combustion system that met the most stringent emission standards in the 1970's.

1967-1972 Research Engineer
General Motors Research Laboratory, Warren, MI

Responsible for the research and development of low emission combustion systems for gas turbine, Stirling and steam engines for potential automotive applications.

4. Consulting

2007-2008 Expert Witness for Orrick, Herrington and Sutcliffe, LLP

Expert witness for the plaintiff in a trade secret case involving diesel emission control systems (represented by Orrick, Herrington and Sutcliffe, LLP). Case was successfully settled after expert testimony. (May 2007 – December 2008)

5. Associated Experience

1965-1966 1st and 2nd Lieutenant
U.S. Army

- 1965 Frankford Arsenal – Responsible for developing improvements in the save capability of high-speed aircraft emergency ejection seats using propellant actuated devices.
- 1966 Cam Ranh Bay, Vietnam – Assistant Adjutant, U.S. Army Depot

1967-1991 Lt. Col. and prior ranks
U.S. Army Reserve

Annual Training (Mobilization Training)– Deputy Chief of Staff for Research, Development and Acquisition (DCSRDA), Department of the Army, Washington, DC
- Responsible for technical analysis of critical powerplant programs for the Army's mobility equipment

6. Professional Affiliations

Society of Automotive Engineering (SAE) – Fellow Member
American Society of Mechanical Engineers (ASME)– Member
Engineering Society of Detroit (ESD) – Member

7. Patents

Issued 29 U.S. patents and numerous foreign patents in the following areas:
- Low emission combustion systems
- Diesel particulate filters
- Adiabatic engine design
- Engine control systems
- OBD II monitor systems
- Traction control

8. Publications

Published 25 technical papers on powertrain research and development in SAE, IMechE, FISITA, ASME, API, NPRA (National Petroleum Refiners Association) and CRC.

9. Significant Awards

- Recognized as an innovator in the automotive industry by being appointed as one of the first Henry Ford Technical Fellows (1994) (technical ladder position equivalent to Engineering Director in Ford Motor Company).
- ASME Soichiro Honda Medal for technical achievements and leadership in every phase of automotive engineering, including 26 patents related to both gasoline and diesel engines (2007).
- SAE Edward N. Cole Award for Automotive Engineering Innovation – For outstanding creativity and achievement in the field of automotive engineering (2006).
- Honored by being invited to present the 2003 Soichiro Honda Lecture at the ASME Internal Combustion Engine Division Meeting (September, 2003). The lecture provided a comprehensive description of the technology incorporated in the first domestic SULEV vehicle.
- Honored by the Inventors Hall of Fame as a Distinguished Corporate Inventor (1997).
- Elected by SAE to Fellow Member Grade in recognition of major technical contributions in the area of diesel engine research (1985).
- Honored with 5 SAE Arch T. Colwell Merit Awards for SAE technical publications.
- Selected as SAE Teetor Industrial Lecturer (1985-86 and 1986-87) and invited to present lecture at multiple universities.
- Received the prestigious Henry Ford Technology Award for development of regenerative diesel particulate filter systems (1986).
- Honored with the SAE Vincent Bendix Automotive Electronics Engineering Award (1983).

10. Professional Service

- Chair, ASME Soichiro Honda Medal Committee (2008-Present)
- Past member of the 21st Century Truck Partnership Study Committee of the National Research Council (2007-2008)
- Past member of the Low Heat Rejection Engines Study Committee of the National Research Council (1985-1986)

- Past participant in Workshop for the National Research Council's Study on "Automotive Fuel Economy – How Far Should We Go?" (1991)
- Past member of the SAE Forum on Sustainable Development in Transportation to provide a technical response to President Clinton's initiative on future technology and the environment.
- Past member and chairman of the SAE Teetor Educational Awards Committee
- Past member of SAE ABET Relations Committee
- Past member of SAE Transaction Selection Committee for Advanced Powerplants and Emissions
- Past member of SAE Gas Turbine Committee (early 1970's)

Appendix G - Acronym List

Acronym List

Acronym	Meaning
AAF	Annual Adjustment Factor
BLS	Bureau of Labor Statistics
CBOM	Comparison Bill of Materials
CMAT	Cost Model Analysis Template
COI	Conflict of Interest
CV	Curriculum Vitae
CVCC	Compound Vortex Controlled Combustion
DI	Direct Injection
DOHC	Double Overhead Cam
ED&T	Engineering, Design And Testing
EPA	Environmental Protection Agency
GDI	Gasoline Direct Injection
GHG	Greenhouse Gas
HCCI	Homogeneous Charge Compression Ignition
HRI	Harbour Results, Inc.
IC	Indirect Cost
ICF	ICF International
ICM	Indirect Cost Multipliers
LD	Light Duty
LTC	Low Temperature Combustion
MAQS	Manufacturing Assumption and Quote Summary
MCR	Material Cost Reduction
MOH	Manufacturing Overhead
MRO	Maintenance, Repair, Other
NA	Normally Aspirated
NTA	New Technology Advances
OEM	Original Equipment Manufacturers
PCM	Powertrain Control Module
PFI	Port Fuel Injection
PPAP	Production Part Approval Process
PSA	Peugeot Société Anonyme
PZEV	Partial Zero Emission Vehicle
R&D	Research and Development
SAC	Supplier Accounted Cost
SG&A	Selling, General And Administrative
TC	Turbo Charged
TMC	Total Manufacturing Cost
UAW	United Auto Workers
VVT	Variable Valve Timing