



**TASK ORDER 0003 UNDER
CONTRACT DTNH22-13-D-00298**

**PEER REVIEW OF “COSTS OF MEDIUM- AND HEAVY-DUTY
VEHICLE FUEL EFFICIENCY AND EMISSIONS REDUCTION
TECHNOLOGIES FOR MY 2019 – 2022”**

**PEER REVIEW REPORT
APRIL 21, 2015**

Submitted to:
**U.S. Department of Transportation
National Highway Traffic Safety Administration**
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1.0 INTRODUCTION

This report documents the results of an independent external peer review of the draft publication, *Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022*, developed by Tetra Tech under contract to Southwest Research Institute (SwRI) for the National Highway Traffic Safety Administration (NHTSA). Eastern Research Group, Inc. (ERG, a contractor to NHTSA) organized this review and developed this report. The report provides background about the review (Section 2), describes the review process (Section 3), and presents reviewer comments (organized by charge question [Section 4] and additional comments [Section 5]). Appendices A, B, and C, respectively, provide reviewer curriculum vitae (CVs)/resumes, the charge to reviewers, and reviewer comments organized by reviewer.

2.0 BACKGROUND

In September 2012, NHTSA competitively awarded a contract to SwRI to conduct research in support of the next phase of federal fuel efficiency (FE) and greenhouse gas (GHG) standards. Tasks included determining the baseline fuel efficiency and emissions levels and technologies of current model year commercial medium- and heavy-duty (MD/HD) on-highway vehicles and work trucks, as well as projections of Phase 2 (post-2018 model year) fuel efficiency and emission reduction technologies. The scope encompassed technologies for chassis and final-stage manufacturer vehicles and trailers, maintenance cost, material application, future design, electric and hybrid propulsion systems, capital investment, retail cost/payback, and any other applicable advanced technologies. Costs, fuel savings effectiveness, availability, and applicability of technologies were estimated for each individual vehicle class category.

This work resulted in three sequential reports, which were peer-reviewed separately due to size. This summary report documents the peer review of the second report, *Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022*. The review document presented an analysis of estimated costs for potential fuel efficiency/GHG improving technologies. Tetra Tech, a subcontractor to SwRI, performed the cost analysis under the guidance and direction of SwRI and NHTSA.

3.0 PEER REVIEW PROCESS

3.1 Reviewer Search and Selection

For this review, ERG identified, screened, and selected six reviewers who had no conflict of interest (COI) in performing the review and who collectively met the following technical selection criteria provided by NHTSA. Expertise in:

- Fuel consumption/GHG reduction technologies for medium- and heavy-duty on-highway vehicles and work trucks, including their engines and trailers.
- Motor vehicle manufacturing processes (for the whole vehicle).
- Incremental costs (direct & indirect) of implementing fuel efficiency technologies.
- Incremental retail prices.
- Life cycle costs.
- Indirect effects of implementing fuel efficiency technologies (e.g., co-benefits, impact on sales, etc.).
- Motor vehicle industry economics for the U.S. domestic market.
- Retail Price Equivalent and/or Indirect Cost Multipliers, including MD/HD vehicle component complexity, innovation, sourcing, materials, production, and lead times.

ERG developed a list of potential candidates who appeared, based on publicly available information, to meet the above criteria. After receiving NHTSA confirmation that the candidates were suitably qualified and had no

obvious COI, ERG contacted these candidates to ascertain their interest and availability to perform the review. Interested candidates provided their CV/resume, completed and signed a detailed COI form, and a signed non-disclosure agreement (NDA). After carefully reviewing this additional information, ERG selected six candidates who collectively best met the selection criteria and had no conflict in performing the review. ERG provided their CVs/resumes, signed NDAs, and certification of lack of COI to NHTSA. After receiving NHTSA verification that the proposed reviewers were appropriately qualified, ERG contracted with the following six experts to conduct the review (see Appendix A for CVs/resumes):

Mr. Bruce M. Belzowski, Managing Director of Automotive Futures, Transportation Research Institute, University of Michigan. Mr. Belzowski has authored or co-authored research reports focusing on a variety of automotive topics, including product development, manufacturer-supplier-dealer relations, globalization, information technology, knowledge management, and human resources. His current research topics include powertrain strategies and powertrain research and development (R&D), intelligent transportation systems (ITS), globalization of the automotive industry, and heavy truck safety technologies.

M.A., English Literature and Theater, University of Michigan, 1980
B.A., English Literature, University of California, Berkeley, 1977

Dr. Roger H. Bezdek, President, Management Information Services, Inc. Dr. Bezdek has 30 years' experience in consulting and management in the energy, utility, environmental, and regulatory areas, serving in private industry, academia, and the U.S. federal government, and is the founder and president of Management Information Services, Inc. – a Washington, D.C.-based economic and energy research firm. His consulting background includes energy technology and market forecasting, oil, coal, natural gas, and nuclear energy analyses, estimating the impacts of renewable energy and energy efficiency, assessment of DOE energy R&D programs, estimation of the costs and benefits of energy systems, assessment of the economic effects of environmental and energy technologies, energy industry forecasting, environmental impact assessments, and creation and management of federal energy programs. Dr. Bezdek is also an internationally recognized expert in economic and energy analysis and forecasting.

Ph.D., Economics, University of Illinois -Urbana

Mr. Sujit Das, Senior Research Staff Member, Energy and Transportation Science Division, Oak Ridge National Laboratory. Mr. Das is program manager of the cost modeling of lightweight materials and clean energy manufacturing programs for the U.S. Department of Energy (DOE). He develops, manages, and leads projects for the DOE Office of Vehicle Technologies and Advanced Manufacturing Office. Mr. Das and his team(s) develop cost models of advanced materials and transportation technologies and decision-making tools for several resource markets and provide market assessments of energy efficient technologies including environmental implications for both domestic and international markets. He has expertise in several multi-disciplinary research areas including, but not limited to, life cycle assessment of aluminum-intensive vehicles; next generation materials with energy/emissions reduction potential in the U.S.; manufacturing process modeling of high temperature stationary fuel cell systems; life cycle modeling of alternative lightweight engine design options; 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; economic analysis of advanced power electronics, electric motors, and intelligent transportation systems; and energy efficiency of distribution transformers.

M.B.A., Management Science and Computer Science, University of Tennessee, 1984
M.S., Metallurgical Engineering, University of Tennessee, 1982 .

Mr. John Fillion, retired Senior Manager of Powertrain and Chassis Materials Engineering, Chrysler. Mr. Fillion has over 30 years experience in the area of materials engineering and development. During his career with Chrysler, he developed applications for elastomers and plastics in the areas of powertrain, chassis, exterior, and interior components, and over the course of several positions was responsible for materials, process, and performance standards for elastomers, fluids, glass and plastics, sheet metal, welding, corrosion, adhesives, paint, castings, forgings, powder metal, heat treatment, and the materials characterization testing laboratories. In 1993, Mr. Fillion, as a charter director, assisted in the formation of United States Automotive Materials Partnership (USAMP), a consortium of Ford, GM, and Chrysler that directed materials research for light-weight vehicles. He retired from Chrysler in 2007.

M.A., Management, Central Michigan University
M.S., Materials Engineering, University of Dayton

Dr. Kenneth A. Small, Professor Emeritus of Economics, University of California at Irvine. Dr. Small specializes in urban, transportation, and environmental economics. Recent research topics include highway congestion, toll-lane demonstration projects, value of time and reliability, fuel taxes, fuel efficiency regulations for cars, and public transit service and pricing. He is especially recognized as an expert in congestion pricing, travel-demand analysis, discrete-choice econometrics, and environmental issues in transportation. Dr. Small was the founding President of the International Transportation Economics Association, and still serves on its Executive Committee. He served four years as Associate Editor of Transportation Research Part B: Methodological, with responsibility for handling submitted papers in the areas of transportation economics and travel demand. He was previously North American co-editor of the interdisciplinary journal, Urban Studies, and continues to serve as member of four editorial boards. Dr. Small received the Distinguished Member Award of the Transportation and Public Utilities Group of the American Economic Association in 1999, and the Distinguished Transportation Research Award of the Transportation Research Forum in 2004.

Ph.D., Economics, University of California at Berkeley, 1976
M.A., Physics, University of California at Berkeley, 1972

Mr. Kenneth W. Vieth III, President and Senior Analyst, ACT Research Company, LLC. Mr. Vieth oversees commercial vehicle analysis and forecasting at ACT and is the company's principal heavy truck and trailer market analyst. He is an advisor to the commercial vehicle OEMs and suppliers, the investment community, trucking companies, and other businesses affiliated with the industry. In 2012, Mr. Vieth was named as the consulting economist to the National Private Truck Council (NPTC) and in 2013 was the top forecaster in the Chicago Federal Reserve Bank's consensus forecast.

B.S., Political Science and History, Southern Illinois University, 1987

3.2 Conducting the Review

ERG provided reviewers with the review document and the charge to reviewers (Appendix B). To kick off the review, ERG organized a 1-hour briefing call. During this call, which was facilitated by ERG, NHTSA described the purpose and development of the review document, and reviewers had the opportunity to ask questions of clarification regarding the charge and review process.

After this call, reviewers worked individually (i.e., without further contact with other reviewers or NHTSA) to prepare written comments in response to the charge questions. Reviewers submitted their written comments to ERG, and ERG provided them to NHTSA. ERG forwarded to one reviewer a request from NHTSA to clarify two comments, and he responded by revising his final comments. ERG then prepared this peer

review report. Section 4 of this report presents reviewer comments organized by charge question, Section 5 presents additional comments provided by reviewers, and Appendix C provides the complete original comments by reviewer. In both cases, comments are presented exactly as submitted, without editing, summarizing, or correction of typographical errors (if any). Any comments not relevant to the review document, though out of scope, have also been included.

4.0 REVIEWER COMMENTS ORGANIZED BY CHARGE QUESTION

This section presents reviewer comments organized by charge question. Comments are copied directly from written comments as submitted by each reviewer and presented in Appendix C.

4.1 Incremental Cost Analysis (Section 3)

4.1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.

Belzowski

- I do not know of any other potential sources for this data, but because many technologies are in the development stage, constant updating of their progress is needed in order for policy makers to make good decisions. We will see this during the mid-term assessment for light duty vehicle CAFE. The regulators meet with the manufacturers and suppliers frequently to discuss where they are in developing and marketing the technologies the industry said they would pursue over the next 10-15 years. And the regulators find that some new technologies that they didn't expect to play a role are now in development. All this communication provides regulators important input that goes along with reports such as this one. It would be nice if the authors could easily update their models dynamically as new information becomes available or else the report will become dated.

Bezdek

The published studies and data cited do not include all key relevant data sources for the target technologies. Numerous additional sources could have been consulted, or at least listed. Examples of some (but not all) of these potential sources are listed below at the end of my formal comments. [see section 5.0 *Additional Comments Provided*]

In the whole draft report, "peer reviewed studies" is mentioned only once, on p. 133. Virtually all references cited in the draft report are not peer reviewed. This is very disturbing and weakens the report's credibility.

Further, of the approximately 45 references listed, there is only one that is a published peer reviewed study (Lepeule, J., F. Laden, D. Docker, J. Schwartz, "Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009," *Environmental Health Perspectives*; 120:965-970, July 2012), and even it does not directly address MD/HD Truck Fuel Efficiency Technology issues.

I have listed at the end of my formal comments some additional sources that could have been consulted. [see section 5.0 *Additional Comments Provided*]. These are meant to be indicative, not comprehensive. It is the job of the draft report authors, not the report reviewers, to conduct a rigorous and comprehensive literature review – including peer reviewed studies published in the literature -- as an integral part of the research.

Das

An extensive literature review was presented in the report's Appendix A although the major information source used was the NRC 2010 report in most cases. Use of a wide range of data sources makes it difficult to assure that the underlying assumptions behind estimates are consistent. For example, the average of low- and mid-values incremental price estimates has been assumed for the incremental price at the lowest production volume. It is likely that the estimates from various sources are not at the same assumed annual production volume of 50,000 besides the fact that the price range in some technology cases has been found to be quite large and the baseline technology assumed to derive the incremental price may not be the same. In addition, estimates used based on a review of various information sources further require that they are truly incremental prices and not costs and in the latter cases an appropriate same scaling factor/multiplier needs to be used. In Appendix A, the term "cost" was used throughout although estimates were used for incremental prices. For the same reasons, the use of word "price" vs "cost" needs to be done appropriately in the report. It is unclear from the report how these important issues were addressed. By taking the average of the range of price estimates to some extent addresses this issue, but a validation of the final estimates in cases where technology has already been commercialized would have been useful. It is unclear, from the individual technology curves starting on pg. 21 of the report, what does the incremental price range shown by the vertical lines at four specific annual production volumes represent including underlying assumptions?

Fillion

The literature review by Tetra Tech appears thorough for the target technologies and the cost estimates appear reasonable for each volume point. The tables and graphs represent a compilation of the cost for each of the target technologies; and the data should represent a valuable reference source for both experts and non-experts that require a working knowledge of the costs for the relevant technologies that might be used for future truck fuel economy improvements. The target technology descriptions in the appendix should be a valuable resource for non-experts working in the area and a useful resource to the experts. While no cost prediction model can be completely accurate, it is expected that the predicted costs, by this report for the target technologies, would be in substantial agreement with the actual measured future costs for the target technologies should they be deployed.

Small

This question is outside my area of expertise.

Vieth

As costing models are not this reviewer's area of expertise, I am not aware that there are any relevant data sources that were overlooked in the literature review of the analysis.

That said, one obvious shortfall in the costing data is a lack of real-world pricing across all currently existing products. Tire pricing in tables 67-69 are just one example. Relying on studies rather than real-world data for existing products seems a bit sloppy given the importance of this regulation. Calling on companies is hard work. On the other hand, going to tirerack.com is not particularly arduous and you can get real-world pricing in real-time across a range of products. Heavily leaning on a study done back in 2002 (reference 28), and some even earlier studies, for an array of technology pricing comes off as not trying very hard.

4.1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

Belzowski

- Very few people will understand why the authors used a squared term in their regression equations. But for reviewers such as myself, I need to know how estimates were generated. I need to know the details. For this report the authors are very thorough about describing what other reports have found about these technologies. One of my issues with the Incremental Cost Analysis is the lack of explanation, either in the body of the report or in the appendices, of how the estimates for each of the variables (production overhead etc.) were created. The authors show the reader the main outline of the analysis, but they do not show the details. I know the details are complex, but I would like to see them, either in the body or in an appendix.
- My other issue focuses on the lack of discussion of the results for each technology. Is the model for a particular technology a good estimate of all the costs/prices or is it a weak model? I have concerns about the strength of the models for some of the technologies. Because of the lack of a teardown analysis that examines all the parts of a technology, the reliance on others' estimates sometimes creates a wide range of possible prices. When I look at the appendices to see what the estimates from other sources are, I see a wide range of estimates for some of the technologies. It looks like the authors are showing this in the vertical bars in the graphs in the body of the report (though this is not noted anywhere that this is the case).
- Nearly all the technologies have wide ranges, whether the technologies are very expensive or even if the technologies are not considered very expensive. Even if a technology is considered less expensive, a wide range of these values will affect the average price as well as the estimates for the components (production overhead, company overhead, etc.) Below, I have broken the technologies with relatively wide ranges into three groups: more expensive technologies with wider ranges, moderately expensive technologies with wider ranges, and less expensive technologies with wide ranges:
 - More expensive technologies
 - Advanced bottom cycling (\$22,500 range)
 - Hybrid-electric powertrains (\$21,000)
 - Diesel APU (\$6,000)
 - Battery APU (\$5,000)
 - Class 4 to 6: Dual clutch automatic (\$1,900)
 - Class 8: Dual clutch automatic (\$5,000)
 - Class 2b and 3 Weight reductions (\$2,000)
 - Class 4 to 6 Weight reduction (\$4,000)
 - Class 8 Weight reduction (\$12,000)
 - Moderately expensive technologies
 - Lean Burn GDI with SCR: Class 2b and 3 / Class 4 to 6 (\$1450)
 - Turbocharging and downsizing: (\$700)
 - Engine downspeeding: (\$2,000)

- Stop/Start diesel: (\$1,000)
- Air handling improvements: (\$725)
- Mechanical turbo compound: (\$1,000)
- Electric turbo compound: (\$1,500)
- Fuel-fired heater (\$600)
- Shore power (\$1,800)
- Boat tail (\$800)
- Full trailer skirt (\$325)
- Full tractor skirt (\$500)
- Class 4 to 6 improved transmissions: gas (\$500)
- Class 4 to 6 improved transmission: diesel (\$600)
- Class 8 improved transmissions: (\$1,700)
- Class 4 to 6 automated manual transmissions: (\$700)
- Class 8 automated transmissions: (\$2,000)
- Automated tire inflation (\$800)
- 6 X 2 axles (\$1,600)
- Less expensive technologies
 - Class 2b and 3 (\$300 range) / class 8 variable displacement pump (D) (\$300 range)
 - Variable valve actuation: Class 8 High 1 and 2 (\$450)
 - Cylinder deactivation: Class 2b and 3 / Class 4 to 6 (\$525)
 - Low friction engine oil: Class 8 (\$95)
 - Engine friction reduction: (\$225)
 - Reduced aftertreatment backpressure: (\$575)
 - Air-conditioner improvements: (\$350)
 - Cab insulation (\$250)
 - Air compressor (\$300)
 - Aero gap filler (\$350)
 - Class 2b and 3 improved aerodynamics (\$425)
 - Class 2b and 3 Improved gas transmissions (\$400)
 - Class 2b and 5 / Class 4 to 6 low rolling resistance tires (\$38)
 - Single wide tires (\$100)
 - Low friction axles and lubricants (\$300)
- Fitting a line through the four points on the graph is very likely the best/most conservative estimate for a set of data, but the practical use one can take away from the wide range of values, I argue, is not as useful as it is for the analyses where the range of costs/prices is narrower. The wide range of values also plays a role in the accuracy of the estimates for components of the Incremental Cost Analysis. Generating estimates for the components (production overhead, etc.) based on this wide range of values needs to be addressed by the authors in order to help the reader make better use of the results.

- P.14 onwards: “Example using the methodology and application of Indirect Cost Factors (ICF)”. I find these “Examples” very confusing. Are they there to show me how all the different combinations of adjusting variables described earlier are used to create the estimates that are used throughout the following tables of technologies? If so, they sow more confusion than clarity. I think it would be much better to walk through one of the technologies, showing all the calculations used to come up with each of the estimates on the graph and in the table. This gives the reader a better understanding of how the authors used all the different adjustments they discuss earlier in the report.
- I can see the regression analysis the authors are using is very complex, but not being able to describe what they are doing makes the whole process less understandable. I’ve used complex equations like this in other reports, and I found that though much of it is lost on the people reading the report, at least showing them the variables that make up one of the equations would be helpful, if not in the main text then in an appendix.

Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

- I think it is a matter of clearly showing what they are doing as well as describing what the results mean. This is missing from this report overall.

Bezdek

The methodology used in the report for determining incremental retail prices contends that it relied on a “thorough literature review” for all target technologies to identify ranges of price points. However, as noted, the literature review was not thorough and contained virtually no peer reviewed publications. The report relied heavily on the NRC study. However, the NRC study is five years old and should have only been the starting point for the research.

The methodology is adequately described. However, it is simplistic and mechanistic and is heavily dependent upon many assumptions. Most of these assumptions appear to be relatively reasonable; some do not.

There is a tendency among researchers – evident in this draft report -- to evaluate technologies under conditions which are best suited to that specific technology. This can be a serious issue in situations where performance is strongly dependent on duty cycle, as is the case for many of the MD/HD technologies evaluated in this report. One result is that the reported performance of a specific technology may be better than what would be achieved by the overall vehicle fleet in actual operation.

Another issue with technologies that are not fully developed is a tendency to underestimate the problems that could emerge as the technology matures to commercial application. This problem is little discussed in the draft report.

Such issues often result in implementation delays as well as a loss of performance compared and increased costs compared with initial projections. As a result of these issues, some of the technologies evaluated in this draft report may be available later than expected, or at a lower level of performance and higher cost than expected. Extensive additional research would be needed to quantify these issues, and regulators will need to allow for them the fact that some technologies may not mature as expected. The draft report should discuss this and related relevant issues.

Das

The quality, scope, and rigor of the methodology used to calculate incremental prices have been adequate by making use of the best available resources, primarily from the prior EPA research. A combination of several

available methodologies was used to derive the final incremental technology price estimates as a function of annual production volume. The reviewer is unaware of whether this approach has been used in any prior such studies as a proxy to detailed vehicle teardown for an initial retail part price breakdown. No backup calculations such as in the form of spreadsheet files were available to determine accuracies of derived estimates. In addition, the statistical curve fitness values for the derived quadratic relationships were unavailable. An excellent job has been done by providing a step-by-step procedure using the methodology for estimating the incremental retail price sensitivity to annual production volume on p.14-16.

The use of indirect cost factors to estimate the decrease in costs as the cumulative manufacturing volume increases over time is somewhat misnomer since this factor was initially applied to the assumed technology retail *price* besides the fact that one of the two major elements of the incremental price is indirect cost. A further description of this factor would have been helpful. The cost element breakouts in the incremental price based on 2010 RTI's 2010 heavy duty truck report seem to be reasonable.

It'd be useful to provide the distinction between High 1 and High 2 Technology Complexity cases. Based on ICF listed on Table 2, the cost reduction for High 1 with increasing production volume is higher than for High 2, implying thereby that incremental price will be higher for more complex technology High 2 than High 1. But the estimates shown by developed relationships in Tables 9 thru 11 indicate otherwise.

Fillion

The methodology used by Tetra Tech is of good quality and scope. Estimating the future cost of technologies not yet deployed cannot be precise. The costs presented appear reasonable and more effort in this area would not bring about much improvement in these cost predictions. Consequently, the cost prediction method is acceptable as is.

Small

The approach used does not provide full confidence that the learning through volume, as opposed to learning through time, is accurately understood. This is important because the cost decrease as a function of cumulative volume has a significant effect on any use of this report. But its estimation is indirect: learning rates are specified as functions of time, not volume (Table 4); and only later are converted to functions of cumulative volumes based on assumed annual production volumes. This indirect approach is correctly noted in the report: "The time based short- and long- term indirect cost factors are used to estimate the decrease in costs as the cumulative manufacturing volume increases over time" (p. 10).

The importance of accurately understanding volume-dependent costs is illustrated by the possibility of technologies whose rapid early adoption become self-reinforcing, as cost declines lead to further adoption; versus others whose slow early adoption becomes self-limiting, due to continued high costs. Apparently a model based on the results of this report can indeed capture these effects, but somewhat by accident since the information is originally derived from assumptions about learning over time, not over volume.

The NRC report (Reference 54), relied upon extensively in this report, discusses hydraulic hybrid vehicles at length. Some justification is needed for why such vehicles are not considered here.

Vieth

In reviewing technology pricing, I tended to focus on those technologies related to heavy trucks (this reviewer's specialty) as well as those technologies with extreme gaps in pricing estimates. The problem this reviewer saw with many of the technologies with large pricing discrepancies was oftentimes a lack of rigor in

checking the results and making sure that what was being considered would fall under the heading “apples to apples.” Several examples follow.

Per the last paragraph in response to question 1.1 above, a second major shortcoming that could also be classified as a lack of rigor, or perhaps inadequate methodology, was the lack of real world pricing for existing products. A week of phone calls and a couple days on the internet could have gone a long way to more relevantly bracketing actual pricing, rather than relying on old reports and inflation adjusting decade-old pricing estimates.

In the case of Classes 2b & 3 Cylinder Deactivation (G) (table 10 & 11), the side note in reference 54 indicates that the low price estimate (\$75) is not an apples to apples comparison, and a mid-point of the side note would be ~\$300, suggesting a still wide, but closer incremental price gap. So, why was an outlier included in the table, or why wasn't the data properly adjusted?

There was an excellent sample of supplier pricing for Auxiliary Power Units (APUs) (tables 42-43). However, pricing data for Low Rolling Resistance (LRR) tires (table 68) was not supplier based and not clearly laid out: Class 8 units, or Class 8 and trailer combo? When the tractor/tractor-trailer denominator wasn't specified (as it was in table 69 examples), it was assumed the references were tractor-only. In the case of LRR tires (table 68), the cost is given as an increase of \$25-\$35 per tire, but in 3 of the 5 references, system cost was put at \$550 (tires only). Given that a traditionally spec'd Class 8 tractor comes equipped with 10 tires, that math works to \$55 per wheel. And again, with tires, there are any number of tire sellers on the web providing comparative pricing across a range of tire types and brands.

For wide-single tires (table 69), the low-end estimate of \$90 from citation 80 appears to be an outlier. The other estimates suggest citation 80 should have been measured as per axle, rather than as a tandem cost: In the other citations, the prices range from a \$140-\$150 upcharge in references 7 and 42, \$175 in references 28, and \$225 in reference 54. Again, not hard to check.

As a final example suggesting that the effort put into the technology pricing section of the report lacked rigor, the Class 8 Reduced Aftertreatment Backpressure (Table 35) serves as an example: Only 2 of 10 citations addressed diesel engines, and one of those two citations, adding a Selective Catalytic Reduction (SCR) system (reference 54, cite 2), is the de facto standard in heavy truck engines today. This effectively leaves one citation for the incremental price estimate.

Given the relative ease in finding some fairly substantive deficiencies in the pricing data, there are significant questions raised regarding the effort expended in finding the best pricing data available. Per the examples presented under question 1.2 in regard to the pricing data, there was a clear lack of rigor in chasing down real-world pricing, a failure to make sure citation comparisons were apples to apples, and the use of citations that don't specifically address the technology in question. Finally, to that I would add the heavy reliance on reference 28 as a pricing guide: While reference 28 undoubtedly cites a great report, I suspect it was even more relevant when it was compiled in 2002.

4.1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?

Belzowski

- P. 27: “In cases where single technologies are combined into a technology package, the price of the package is defined as the sum of the prices of the components.” While this seems reasonable, one would think that a package/system of technologies should reduce costs.

- P.13: Compared to the North American light duty market, the market for Class 2b through Class 8 trucks is small. This is a key issue for any company considering investing in developing these technologies. This means that various suppliers and manufacturers that are developing and selling new technologies are fighting over small shares of the market and potentially low volumes. Of course, a company that comes up with a great new technology will have the lead for a few years, but industry leadership in one technology does not last long in the auto industry because competitors quickly adjust and develop their own versions of a technology, if they think they can do it profitably. Also, the volume assumptions for technologies do not seem to account for potential global volumes as well as North American-only volumes. Auto manufacturers and suppliers are global, and they make business decisions based on potential volume wherever it is.

Bezdek

Addressed above.

Das

The underlying factors and assumptions used in the analysis based on the recent published research seem to be reasonable. Most developed technology incremental price curves showed a reduced marginal price with the increasing production volume, and the price leveling off at annual production volumes beyond 600,000.

Fillion

The factors and assumptions used by Tetra Tech are reasonable as viewed from the career experience and perspective of this peer reviewer.

Small

Cost reductions due to learning and cumulative volume are assumed to apply only to indirect costs. Yet it seems likely that direct manufacturing costs would also decline due to learning and cumulative volume. For example, manufacturing process improvements could lower the requirements for labor and materials.

Vieth

Per previous comments, pricing analysis is not a part of this reviewer's background. However, a lack of real world pricing and a reliance on some very old analysis (even after adjusting for inflation), and in some cases what is perceived as sloppy math, or at a minimum vague citation, leaves one wanting a higher level of diligence.

4.1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

Belzowski

- P. 14 "It is important to note that because prices are for cumulative volumes, volumes across vehicle classes may be additive. For example, if the same gasoline engine is used in both Class 2b&3 and Vocational vehicles, the industry total volume for a technology on that engine will include volumes from both vehicle categories. As a result, the incremental price of the technology may be lower than the price according the volume in a single vehicle category." I think this should be noted where possible in the graphs, so the reader knows when the authors are crossing boundaries and when they are not.

Bezdek

Most of the price and breakouts presented for the various vehicle technology categories are credible, but minimally so. They are, in general, not adequately supported due to the deficient literature review and inadequate research conducted. They require fixed, and sometimes heroic, assumptions and a lot of faith in the algorithms utilized.

For example, some technologies, such as certain aerodynamic features, automated manual transmissions, and wide-base single low-rolling-resistance tires, are already available in production. On the other hand, some of the technologies discussed in the draft report are in varying stages of development, while others have only been studied using simulation models.

The NRC recommended that regulations should target the final stage vehicle manufacturers, since they have the greatest control over the design of the vehicle and its major subsystems that affect fuel consumption. Component manufacturers will have to provide consistent component performance data. As the components are generally tested at this time, there will be a need for standardized test protocol and safe guards for the confidentiality of the data and information. It may be necessary for the vehicle manufacturers to provide the same level of data to the tier suppliers of the engines, transmissions, after-treatment and hybrid systems.

Simulation modeling should be used with component test data and additional tested inputs from powertrain tests, which could lower the cost and administrative burden yet achieve the needed accuracy of results. The program should represent all the parameters of the vehicle (powertrain, aerodynamics, and tires) and relate fuel consumption to the vehicle task.

A number of the technologies, such as adaptive cruise control, predictive cruise control, and navigation and route optimization are currently being applied by the trucking industry without any regulation because the owners and operators view the reduction in fuel costs as good business. What does this imply for the feasibility and optimality of some of the proposed regulations discussed in the draft report? The report recognize this and discuss the implications.

Detailed Comments on Section 3

P. 9, ¶ 1: “The methodology used here for determining incremental retail prices relies on a thorough literature review for all target technologies to identify ranges of price points. The data reported here draw heavily upon the most recent National Research Council study of medium- and heavy-duty vehicle technologies.”

The NRC study referred to is already more than five years old, the research for the NRC study was conducted six or seven years ago, and the data and sources used in the NRC study are at least 5-10 years old. Some of the references cited in the Tetra Tech draft report are decades old, and in any event, the literature review was not sufficiently “thorough”.

P. 9, ¶ 2: “The ranges of values found in the literature are scaled to project incremental prices using manufacturing volume-dependent cost curves.”

It is not clear what this sentence is supposed to mean.

P. 9, ¶ 4: “Indirect costs are derived from direct costs using an adjusted multiplier.”

Can this adjusted multiplier be quantified and illustrated simply?

P. 9, ¶ 4: “The first main factor is derived from research conducted for the U.S. Environmental Protection Agency (EPA) and reflects manufacturer costs that are difficult to allocate to specific production activities, such as R&D, corporate operations, dealer support, and marketing.”

The references cited are EPA reports, some of which have been known to be incestuous and not necessarily rigorous, objective, or credible. Further, these were not peer-reviewed.

P. 10, ¶ 1: “The relative contributions of each of these elements to the total indirect cost are based on research by Argonne National Laboratory for the U.S. Department of Energy that examined and modified Argonne National Laboratory’s incremental cost components of implementing new vehicle technologies.”

The references cited are DOE lab reports: They are not peer-reviewed and some are decades old.

P. 10, ¶ 2: “The second main factor of the adjusted multiplier reflects improvements in the manufacturing process that take place as the technology matures. As described by the Center for Automotive Research, process efficiencies that are learned over time are captured in this type of cost reduction and are expressed as an annual percent improvement from the previous year.”

How will these be affected (positively or negatively) by the mandated MD/HD fuel efficiency improvements? Was this issue even considered here? If not, why not?

P. 12, ¶ 2: The indirect cost factors and the manufacturing process improvements then are multiplied together to derive the adjusted multipliers that make up the volume-dependent technology cost curves for each of the identified technologies.

This sentence is nearly incomprehensible.

P. 12, ¶ 3: A teardown analysis was not performed in this report to determine the breakout between the direct and indirect cost elements.

Why was not a teardown analysis conducted? The NHTSA standards that will eventually result from the work being reviewed here will be extremely important, will likely cost industry, transportation companies, and consumers hundreds of billions of dollars, and will have very significant impacts on the U.S. economy. Accordingly, appropriate resources, time, and effort should go into developing the standards – including teardown analyses, simulation analyses, pilot programs, etc.

Further, the contractor could have used simulation modeling with component test data and additional tested inputs from powertrain tests that could lower the cost and administrative burden but, at the same time, achieve needed accuracy of results.

Does Tetra Tech (or NHTSA) intend to conduct a pilot program to “test drive” the certification process and validate the regulatory instrument proof of concept? Are any similar programs planned by Tetra Tech or NHTSA?

P. 12, ¶ 4: To estimate the cost element breakouts in the incremental price, the relative cost contributions for truck manufacturers in RTI’s 2010 heavy duty truck report were used.

RTI’s study was conducted five years ago for EPA and was not peer-reviewed. Were any other sources consulted here?

P. 17, Table 10: what is meant by “Vocational?” This should be defined up front.

Das

The incremental price and breakouts presented for the various vehicle technology categories seem to be credible and adequately supported. The share of direct vehicle manufacturing cost to the total incremental price increased with the increased production volume as shown in Tables 5 thru 8. Also, the share of direct vehicle manufacturing cost decreased with the increased technology complexity. Validation of price breakouts using a few example technology cases considered would have been useful.

Fillion

The tables and graphs from the tables are credible and properly supported. They will be a useful resource for the readers of the report.

Small

The text on p. 10 indicates that only the components of indirect cost, rather than their total, is further broken down using the volume-dependent cost contributions of Tables 5-8. If this statement is true, then the time path of overall cost reductions due to learning is represented solely by the three numbers given in Table 4. These numbers appear to be judgmental based on averages over widely varying conditions, and are not an adequate basis for estimating the effects of learning and cumulative production volume.

If the statement on p. 10 is not true, then the actual volume-dependent cost decline is hidden in Tables 5-8. In that case, the brief citation in note 8 (p. 13) is inadequate to support such an important part of the cost methodology.

Figures 1 through 91 constitute the main results, but this is very spare way to present them. This conciseness is no doubt needed to present the large number of technologies considered, but the format makes no distinction between major and minor technologies, and is inadequate for the former. Specifically, it would be valuable to provide more detail for selected technologies that are likely to be important to regulatory design. I suspect one such technology is hybrid electric, due to its very high incremental cost and its popularity for light-duty vehicles. In this case, and probably others, the report needs to summarize the analyses in the cited references, the degree of certainty, the likelihood of the numbers being up to date, and the likelihood of major changes in the technologies and/or their incremental costs that may occur between now and the time regulations would go into effect.

In Figures 1 through 91, I presume the unexplained error bars surrounding the line for total incremental price represent the high and low end of the ranges. This form of presentation uses the same symbols often used to represent statistical measures of uncertainty behind scientific numbers, but there is no corresponding statistical concept here. Rather, it seems that the curve shown is simply the midpoint of the range. Using the midpoint as a best estimate implicitly assumes that the uncertainty surrounding that estimate is symmetric, which in this case would mean that the range limits are equally likely and there are no intermediate cost estimates that are relevant to understanding the uncertainty. It is unlikely that such assumptions are valid. More likely, there is a range of estimates whose distribution might suggest a most likely value different from the midpoint between the two most extreme estimates. I can understand that it is not practical to provide a thorough analysis of the uncertainty in each estimate for these 91 technologies, but it must be possible for some of the more important ones and this is needed for credibility of the resulting numbers. (see also comment above)

Vieth

While there appear to be good levels of supporting documentation, the disparate conclusions drawn on pricing suggest that not all of the supporting documentation answers the same question. This phenomenon is illustrated in the very first technology presented in Table 1, the “Class 8 Advanced Bottoming Cycle.” The cost estimates range from somewhere between \$7,200 and \$30,200. Obviously, a better understanding of the cost and maintenance of adding a waste-heat capture system is needed: At \$7,200, advanced bottoming is an expensive solution and will disrupt the demand cycle pre and post mandate, but with a healthy boost to fuel economy, say 10%, there is a visible path to payback. At \$30,200, we are talking about a mandate so expensive that even with a robust fuel economy payback, commercial vehicle production for the United States, after a massive prebuy in front of the mandate, would be all but shut down for multiple years post-mandate and truckers would focus their efforts on maintaining existing fleets.

Based on ACT Research analysis, in the \$7,200 and \$30,200 examples above, both with 10% fuel economy gains, the period to payback in the first example for a fleet running 90,000 miles/year would be a not-unreasonable 28 months. In the second example, payback is at an illusory 110 months.

There are other high dollar technologies with wide variance in the cost estimates. Class 8 diesel APUs are a good example, with prices ranging from \$6,000 to \$12,000. Again, the wide price disparity suggests two different outcomes in terms of market acceptance and impact on the demand cycle for Class 8 units. Additionally, one company under reference 54 differentiates their price to include Diesel Particulate Filters (DPFs) and an additional \$3,000 for the California market, raising the question regarding the rest of the estimates: are DPFs included or not? If DPFs are not included, perhaps the range for DPF costs needs to be set higher by \$3,000. *And, to the extent that a large portion of the fleet travels to California, California Air Resources Board (CARB) regulations, especially for the long-haul over-the-road market essentially become de facto rules for national carriers, so should be considered in any discussion regarding the heavy truck market.*

Hewing back to Hybrid Electric Vehicles (HEVs) in tables 40 through 41, with pricing estimates ranging from \$9,000 to \$50,000 from the low end of Class 2 to the high end of Class 8, these are the kinds of solutions that will put demand on hold, cause tradespeople and truckers to drive older equipment, and by extension make the roads less safe for all. Additionally, in the case of Class 8, where something like half of the loads weigh-out, the addition of sufficient batteries would eliminate payload, causing a greater need for trucks to do the same amount of work.

4.2 Life Cycle Costs (Section 4)

4.2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories? If not, what can be improved and how?

Belzowski

- Two major issues are of concern for this section: Missing data and timeliness. There is a lot of missing data in this section. This makes it of less value to the policy makers, except for technologies where data is available. But then there is the issue of timeliness. It is 2015. Showing me production volume for 2012 is useless at this point in time. It makes me wonder how old the data is in the section overall. Some of the lifecycle costs have probably not progressed much since 2012, while others probably have. This is always an issue with research that is focused on developing technologies. By the time the report is out, some of the lifecycle costs have already changed, while others are still where they were in 2012. I think there

needs to be a discussion of this issue in the report in order to help the reader who may want to use the information for policy decisions. It sounds like I'm asking the authors to update this section or maybe drop it altogether if the estimates are dated at this point.

- For the Lifecycle Analysis, I was expecting the results of this analysis to be rolled into the Incremental Cost Analysis (or vice versa), but too much missing data in this section looks like it precludes this happening. The authors note that others have addressed this issue more thoroughly begs the question of whether this section should even be in the report or maybe the results of the other reports should be incorporated into this section.

Bezdek

This section presents information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories that is, perhaps, minimally sufficient. My comments on the deficiencies of the previous section apply here.

NRC recommended that any regulation of MD/HD fuel consumption should use Load Specific Fuel Consumption as the metric and be based on using an average (or typical) payload based on national data representative of the classes and duty cycle of the vehicle. Why is this not discussed in the draft report?

The fundamental engineering metric for measuring the fuel efficiency of a vehicle is fuel consumption -- the amount of fuel used, assuming some standard duty or driving cycle, to deliver a given transportation service, for example, the amount of fuel a vehicle needs to go a mile or the amount of fuel needed to transport a ton of goods a mile. For light-duty vehicles, the CAFE program uses mpg. This measure is not the appropriate measure for MD/HDs, since these vehicles are designed to carry loads in an efficient and timely manner.

The project could have used several actual MD/HD vehicles, including various applications, and developed the approach to component testing data in conjunction with vehicle simulation modeling to derive LSFC data for these vehicles. The actual vehicles could also be tested by appropriate full-scale test procedures to confirm the actual LSFC values and the reductions measured with fuel consumption reduction technologies in order to validate the evaluation method.

Research could have established fuel consumption metrics related to the task associated with a particular type of MD/HD vehicle, and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo carrying capacity. Research is required to determine whether a system of standards for full but lightly loaded ("cubed-out" MD/HD vehicles) can be developed using only the LSFC metric or whether these vehicles need a different metric to properly measure fuel efficiency without compromising vehicle design.

Regulation of MD/HD fuel consumption should use LSFC as the metric and be based on using an average (or typical) payload based on national data representative of the classes and duty cycle of the vehicle. Standards could require different values of LSFC due to the various functions of the vehicle classes. The draft report should use a common procedure to develop baseline LSFC data for various applications, to determine if separate standards are required for different MD/HD vehicles that have a common function. Data reporting or labeling should state a LSFC value at specified tons of payload.

Das

This section completely lacks the currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. Life cycle costs tables were presented by the individual identified technologies but limited to only three cost categories, maintenance, replacement, and

residual value. In most cases, estimates were shown as TBD and NNI indicating that the data was unavailable. In a few cases, estimates were shown without providing any reference for the data source used. In addition, fuel savings -- the major component of life cycle costs for fuel efficient technologies is completely missing. There was just a mention of it that fuel savings are determined from SwRI are not being included here.

Fillion

The term "Life Cycle Costs" is inappropriate for this report. Since this report is fundamentally driven by environmental concern of CO2 generation, the reader of the report legitimately would expect an environmental definition of the term life cycle. The expectation would be to read a comparison of the CO2 generation before the deployment of the target technologies compared to the CO2 generation over the life of the vehicle after the deployment. The report discusses the changes in the maintenance cost of the vehicles over the vehicle life time as a result of deploying the target technologies. The recommendation is to change section 4 title to "Vehicle Life Maintenance Cost". Using the definition of maintenance cost for this study, the information represents a good compilation of the vehicle life maintenance cost for each of the target technologies. The majority of the technologies were listed as no net increase (NNI) which is logical and what would be expected. The readers of the report will understand that life maintenance costs will have a small effect on the overall cost of the vehicles, with most of the costs associated with increases in battery and tire maintenance cost. With the nomenclature changes suggested this section is acceptable as written.

Small

It is mostly adequate. See however comment 2.2-1 [4.2.2 of this report].

Vieth

As I am not a trucker, leasing company, OEM, or parts supplier, my qualification to answer questions regarding life-cycle costs are limited.

That said, given that there are 37 tables (numbered 12 to 48) under Section 4 of the base report on life cycle costs, and only one paragraph touching on methodology/providing any explanation at the start of the section, there is absolutely no support/justification for the maintenance and replacement conclusions reached throughout this section.

And again, getting to the level of diligence in the technology report broadly, for most technologies, "To Be Determined" (TBD) is a favored choice for maintenance, and NNI (No Net Increase) is liberally used under the replacement cost heading. It is hard to believe that the addition of a variable displacement pump (Table 13), for example, will have "NNI" for maintenance or replacement, especially given an "n/a" life cycle interval, or that a system that might add \$30,200 to the cost of a vehicle, Class 8 Advanced Bottoming Cycle (Table 12), would have "NNI" replacement cost and an "NNI" residual value at the end of first owner life (which is also not quantified).

4.2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

Belzowski

- I can't address this point other than to say that there to be too much missing data for too many technologies.

Bezdek

The life cycle cost elements presented are minimally credible. They are not adequately supported. My comments on the deficiencies of the previous section apply here.

When there are several fuel-saving options and complex truck operating conditions, performance standards are likely to be superior to specific technology requirements. Where in the draft report is this discussed?

Increasing vehicle size and weight limits offers potentially significant fuel savings for the entire tractor-trailer combination truck fleet, but this would have to be evaluated against increased costs of road repair. Case studies demonstrate that potential fuel savings of up to 15 percent or more are possible – savings that compare very favorably with most of the technologies discussed in the draft report. Further, these savings are similar in size but independent and cumulative of other actions that may be taken to improve fuel consumption of vehicles; therefore the net potential benefit is substantial. The draft report should discuss what is required to implement these and analyze how the potential fuel savings and other benefits of such liberalization can be realized in a way that maintains safety and minimizes the cost of potential infrastructure changes. This discussion should include issues such as regulatory limits that currently restrict vehicle weight and that freeze LCV operations on the Federal Interstate System, establishing a regulatory structure that assures safety and compatibility with the infrastructure, and changes that would be necessary to permit reasonable access of LCVs to vehicle breakdown yards and major shipping facilities in close proximity to the interstate system.

Intelligent transportation systems enable more efficient use of the existing roadway system by improving traffic flow and reducing or avoiding congestion. This should be discussed in the report.

For example, intelligent vehicle technologies provide fuel consumption reductions by taking advantage of knowledge of the vehicle's location, terrain in the vicinity of the vehicle, congestion, location of leading vehicles, historical traffic data, and other information, and altering the speed of the vehicle, the route the vehicle travels, or, in the case of hybrid electric vehicles, altering the power split ratio. These fuel savings may not show up in fuel consumption tests, and this should be recognized in the analysis.

The report could obtain data on fuel consumption from several representative fleets of MD/HD vehicles. This would provide a real-world reality check on the effectiveness of the proposed regulatory design on the fuel consumption of MD/HD fleets in various parts of the marketplace and in different regions of the country.

Detailed Comments on Section 4

P. 112, ¶ 1: "This section presents the information currently available on the vehicle life cycle impacts of the identified technologies in the various vehicle categories."

There is more information currently available than is included in the draft report.

Das

A few life cycle cost elements were only presented and even in those cases have not been credible and adequately supported. Specifically, no fuel savings estimates for various technologies were provided.

Fillion

The maintenance cost elements are credible and properly documented.

Small

In Tables 12-48, the actual “residual value” is likely to depend on the form of regulations, and thus may not be predicted by past experience. For example, the note to Table 47 says “Negative residual value represents the lower resale value of a 6x2 tractor when compared to 6x4 tractors.” The problem is that this point of comparison (the price of a used 6x4 tractor) can itself depend on regulations. If regulations directly discourage use of 6x4 tractors, then their price would fall as a result, so this predicted negative residual value might not actually occur. On the other hand, if regulations discourage new 6x4 tractors but do not discourage a firm from purchasing a used 6x4 tractor, the value of such used tractors might be enhanced due to their scarcity, making the negative residual of a 6x2 tractor even larger.

Vieth

Comments pertaining to question 2.1 apply to this question as well: The life cycle cost elements are presented, but they are not supported with commentary or any description of how estimates were derived. Additionally, there is not a consistent standard for measuring changes in maintenance costs: In some cases it is cents per mile, in others it is on a percentage basis (but without a baseline from which to derive cost in cents per mile).

Using Table 12, the first table in the section, as an example, how was the \$0.003 cents per mile increase in maintenance for Class 8 Advanced Bottoming Cycle derived? Given the inherent number of parts in a system that could add up to \$30,000 to the cost of a Class 8 truck, can we believe that annual maintenance over 100,000 miles will only be \$300? Further, does that maintenance number include any ancillary costs for disposal/storage of the steam generating fluids? While not discussed, are these fluids inert, and will truckers’ maintenance shops require special training for their handling? [Note that the Appendix, Table 1, citations 7, 58, and 60 all mention steam, suggesting that a fluid is a part of the solution.]

Similarly, in Table 14 on Variable Valve Actuation a 10% increase in maintenance is cited: In Table 12, the measure was cents per mile. Now, we have arrived at a 10% increase at 100,000 miles. What does 10% represent in terms of cost?

As a final example, in Table 23 on Stop/Start, the table shows that brake wear will drop 5% over 45,000 miles, but a \$455 battery will be required at 100,000 miles. Factoring for the net impact is impossible with the data provided. Additionally, there is no background on how the 5% brake wear savings over 45,000 miles was derived.

4.3 Indirect Effects (Section 5)

4.3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

Belzowski

- This analysis seems to have covered the relevant indirect effects, but like the lifecycle section, I was expecting the impact of these effects to be incorporated into the Incremental costs models (or vice versa).

Bezdek

No: In general, this whole section is very weak and needs to be strengthened and expanded. The discussion is basically generic and evidences little serious research or analysis.

Elasticity estimates vary over a wide range, and it is not possible to calculate with very much confidence what the magnitude of the “rebound” effect is for MD/HD vehicles. In medium- and heavy-duty trucking, the “rebound” is a more complex phenomenon and has been studied less than for the light-duty vehicle effect. Thus, it may not be valid to apply the light-duty rebound estimates here.

Standards that differentially affect the capital and operating costs of individual vehicle classes can cause purchase of vehicles that are not optimized for particular operating conditions. The complexity of truck use and the variability of duty cycles increase the probability of these unintended consequences, and the draft report should recognize this.

Some fuel efficiency improving technologies will add weight to vehicles and push those vehicles over federal threshold weights, thereby triggering new operational conditions and affecting, in turn, vehicle purchase decisions. Did the report conduct any research to assess the significance of this potential impact? Further, if the vehicles are getting heavier, what implications does this have for safety?

For example, recent research has found that CAFE regulations have had the unintended consequence of greatly increasing the weight of LD trucks, with negative consequences for safety. Is there the possibility of something similar happening with MD/HD regulations? The draft report should discuss this.

Similarly, if the vehicles are getting heavier, what implications does this have for road and infrastructure impacts?

Certain fuel-saving technologies will add to vehicle weight, affecting operators’ costs in three ways. First, transporting the extra weight itself increases fuel costs, partially offsetting the fuel savings the technologies allow.

Second, in MD truck applications, the extra weight may increase the loaded gross weight of some present Class 2 vehicles to over 10,000 lb. and of some present Class 6 vehicles to over 26,000 lb. Exceeding these weight thresholds will subject companies operating the vehicles to federal and state motor carrier safety regulations. A truck operator who has not previously been subject to these motor carrier safety regulations or to CDL requirements and is considering whether to adopt new vehicles with fuel-saving technologies and higher weight that would trigger the regulations will have several options. The operator may acquire the heavier vehicles and comply with the regulations or specify offsetting weight-saving equipment in order to stay under the threshold, or acquire smaller trucks than previously used – and thus use a larger number of smaller vehicles. Vehicle manufacturers may decide to market new vehicle designs that facilitate the latter two choices. Any of these choices will increase the operator’s truck transportation costs, and the operator will select the one with the least cost.

Third, in heavy-duty operations in which trucks are sometimes loaded to the 80,000-lb. legal gross weight limit that applies on most major U.S. roads, and in operations in which trucks are sometimes loaded to axle weight limits (e.g., refuse haulers, dump trucks), the added weight of some fuel-saving devices (without concomitant vehicle weight-reducing materials) will reduce cargo capacity, increasing average cost per ton-mile and necessitating more vehicle-miles of travel to carry a given quantity of freight. In an operation in which trucks are almost always loaded to the gross weight or axle weight limit, the added cost will be proportional to the loss of payload. For example, the payload of a truck loaded near the 80,000-lb. limit is about 50,000 lb., so an additional 500 lb. of fuel-saving devices would reduce capacity and increase average

cost per ton-mile in an application in which trucks are usually loaded to the gross weight limit. The draft report should at least discuss these issues.

Some fuel efficiency improving technologies will reduce cargo capacity for trucks that are currently “weighed-out” and will therefore force additional trucks on the road. What research was conducted here of this potential impact?

Economic analysis of pre-buy and low-buy impacts for some trucks found that the low-buy “dip” was actually more substantial than the pre-buy “peak” and that there was thus a net decrease in sales over this period. A net downturn in sales also indicates that a portion of vehicle owners may be keeping their older units on the road longer (assuming freight demand levels do not decrease substantially). The aggregate impact of all of these factors was estimated to result in a net increase in national annual NO_x emissions, relative to the case without pre-buy/low-buy and elasticity effects. What implications do these findings have for the regulations discussed in the draft report?

The draft report does not adequately address the issue of class shifting. When manufacturers build vehicles, they make trade-offs related to various vehicle attributes in order to produce a vehicle that is most attractive to a given market segment. For example, manufacturers regularly need to balance issues of performance, cost, and fuel efficiency. In cases where regulation incentivizes a certain class of vehicles to meet a fuel efficiency standard at the expense of performance, a potential buyer may choose to purchase a larger class vehicle to offset the performance losses. This behavior leads to less efficient vehicles on the road -- exactly the opposite effect of what the NHTSA efficiency standards are supposed to achieve. This is referred to as “consumer class shifting,” and it can also occur if the cost of different vehicle classes is affected disproportionately by the regulations. For example, requiring aerodynamic fairings on all Class 8 vehicles may cause some companies that currently use these vehicles on long-haul operations to choose smaller, less efficient vehicles rather than invest in the fairings. Others, however, will find they will have to add fairings that provide little benefit at high cost. The level of shift depends on how a regulation affects different vehicle classes and the relative costs across classes. The draft report should discuss class shifting issues and their potential significance.

Was any type of economic/payback analysis based on fuel usage by application and different fuel price scenarios conducted? Operating and maintenance should be part of such an analysis.

Das

Most important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emission reduction technologies have been discussed with estimates available in some cases, thereby limited consideration can only be given in the subsequent desired life cycle analyses. It is unclear why energy security premium on Table 51, p. 134-135, would decrease thru the year 2030 initially, followed by a decrease in 2035+.

Fillion

The analysis presents the important indirect effects that may result from the potential technologies deployed to improve fuel economy. The reader will gain the understanding that fleet turnover and rebound are subjects that will be affected by the future decisions. The study is correct in stating more information is needed to quantify the importance of fleet turnover and rebound. The discussion on incremental vehicle weight, manufacturability and product development, maintenance, repair and insurance are useful to the reader in that the discussions raise the awareness of the issues. The reader will also gain the understanding that these issues are relatively minor parts of the overall new technology discussions. The section on potential issues regarding human health effect, environmental co-benefits, and congestion could be deleted

with no impact on the quality of the report. The quantitative effects that new technologies will have in these environmental areas is not well understood and the reader of the report will not gain much insight into these issues other than the fact that they are subjects that may be discussed in the future.

There is a glaring omission from the report that might be included in this section, but should be included somewhere in the report; perhaps its own section would be best. A reasonable expectation for the reader of the report is to gain an understanding of the cost-to-benefit ratio for each of the target technologies. Imagine a manager hearing a presentation from his engineers regarding approval to deploy the target technologies in the truck fleet under his direction. He would want to know how much does the target technology cost, how long does it take to deploy, and what is the payback time for the investment. For each target technology there is a fuel economy improvement and a cost. The manager would want to see a chart that says at \$4 per gallon for fuel the payback is so many years, \$6 per gallon a shorter payback, and for \$8 per gallon for fuel an even shorter payback. Perhaps the manager could give this report to his engineers and ask them to use the data in the report to build such a table; however, this is work that Tetra Tech should do and provide to the readers of the report.

Small

The breadth of coverage and understanding of the issues is appropriate and impressive.

A potentially important omitted indirect effect is that on road wear. Changes in number of tires, vehicle weight, and VMT can all affect road wear, and hence road maintenance costs.

Vieth

One thing that was not apparent in this section, nor anywhere in the document, was a recognition by the writers that the goal of the regulation should be the biggest bang in fuel economy/greenhouse gas reduction for the fewest bucks and that a cost-benefit analysis should be applied to regulation to ensure that buyers of equipment are encouraged, rather than dissuaded from upgrading their fleets. This is especially true if the purpose of the regulation is to facilitate clean air, rather than to change truckers' buying habits as was acknowledged in the first sentence of the second paragraph on page 130, "... reduced operating costs can potentially affect the turnover of vehicle fleets." The only misstatement in that snippet is the word "potentially." Changes in operating costs have and do impact truckers' buying decisions.

Along those lines, and acknowledging the business cycle as a facilitator of buying behavior in 2006-2007, the sentences indicating that the run-up in sales in 2006 "may be partially attributable..." and the falloff in sales in 2007 "may be partially attributable..." are wrong: While the size of the prebuy ahead of EPA'07 is debatable (was it 80,000 or 90,000 units?), there is no "may be" in fact that a prebuy occurred. Whether looking at order, backlog, or production data from the period, medium duty (MD) and heavy duty (HD) truck buyers overbought trucks starting in 2005 and through 2006 to initially avoid a punitive mandate that raised costs and tax liabilities, increased vehicle complexity, and by extension maintenance. Neither the sharp rise in demand in 2006, nor the sharp plunge in 2007 is justified by macroeconomic data: Given that the economy was strong through 2006, why did order activity collapse in late Q2'06? And with little difference in late 2006-early 2007 GDP (Q4'06, GDP was 3.2% (Q/Q SAAR), while in Q2'07, GDP was 3.1%), why did sales collapse so dramatically in 1H'07? For all of 2007, the ATA's Truck Tonnage Index fell 1% from 2006, but U.S. Class 8 build and sales volumes fell by 55% and 46%, respectively.

Given the gross "may be" misstatement of the situation in 2006-2007, a history lesson to correct the public record follows:

Not only did trucker have the willingness to initially avoid the technology, because a mandate with no payback for the equipment buyer hit at the top of truckers' profit cycle, they also had the ability to avoid the technology. The attached two years of data, from September 2005 through August 2007 and gathered by ACT Research Co., definitively show the impact of the EPA'07 mandate on demand in 2006 and 2007:

As well, the data suggest that a major prebuy was narrowly missed ahead of the EPA'04 mandate, the timing of which was accelerated by the engine manufacturers' Consent Decree by five quarters. But for the fact that credit was essentially unavailable, used equipment prices were at worst in history levels, trucker profitability was also at worst-ever lows, and there was generally complacency amongst the Class 8 trucking community towards EPA mandates, there would have been a fairly large prebuy – again for a mandate with no path to payback: a significantly higher new truck price, *reduced fuel economy*, and increased maintenance costs. While there was a willingness on the part of truckers, worst-ever market conditions meant that the ability to buy was missing. While the prebuy is not visible at an annual level, it can clearly be seen in the monthly data:

For a period of seven months, November 2001 to May 2002, U.S. Class 8 orders (trucks and tractors) were more than double the seven month periods immediately preceding and following:

	US CL8 TOTAL	US CL8 TOTAL	US CL8 TOTAL	US CL8 TOTAL
	<u>NetOrds</u>	<u>Backlog</u>	<u>Build</u>	<u>RSales</u>
Sep. 2005	18,564	134,867	23,516	22,036
Oct.	21,375	131,754	24,972	22,776
Nov.	24,504	135,951	20,799	21,231
Dec.	30,249	147,604	18,940	23,738
Jan. 2006	34,764	158,622	23,784	19,758
Feb.	32,916	167,066	23,070	20,891
Mar.	39,536	180,488	25,736	26,477
Apr.	21,627	177,944	22,887	24,718
May	20,031	170,805	26,814	25,590
Jun.	13,911	163,645	21,811	25,705
Jul.	10,637	148,669	23,628	22,504
Aug.	13,205	130,267	28,070	24,255
Sep.	8,436	112,495	25,989	23,879
Oct.	11,689	95,170	29,083	25,545
Nov.	13,311	82,424	26,054	23,241
Dec.	12,675	76,716	19,254	27,093
Jan. 2007	5,033	61,804	21,184	19,250
Feb.	6,965	51,873	16,915	17,072
Mar.	8,215	44,031	15,834	16,763
Apr.	6,076	41,576	8,456	13,902
May	8,897	42,064	7,998	12,576
Jun.	7,534	40,438	8,775	11,010
Jul.	10,170	41,048	7,493	10,541
Aug.	9,347	40,270	9,411	10,288

USC8 net orders	Units (Avg./Mo.)
April'01 - October'01	7,500
November'01 – May'02	16,100 (+147%)
June'02 – December'02	6,800 (-58%)

Build activity was not as condensed as orders, but nearly so. In the eight months covering the build ramp, production was over 50% higher than in the preceding eight month period, with a Rorschach-like trough period post mandate:

USC8 Build	Units (Avg./Mo.)
July'01 - February'02	9,100
March'02 – October'02	14,100 (+54%)
November'02 – January'03	9,600 (-32%)

The two examples of prebuy, one large and one small, occurred when truckers' costs outweighed the benefits derived by the technology. Likewise, there was no prebuy ahead of EPA regulations in 1988, 1991, 1994, 1998, or 2010, nor in the face of the CAFE'14 mandate. As mentioned in this review's opening comments [see section 5.0

Additional Comments Provided], the sharp rise in new Class 8 truck prices, with no path to payback, has caused a sharp rise in overall fleet age in the United States as truckers have had to keep trucks longer to justify new vehicle costs. Also noted was the fact that since 2008, what had been an extended period of falling heavy truck related highway fatality rates, has basically been stalled since 2009.

Regarding the rest of section 5, there is a sense in reading under the Ton-Miles Travel and Rebound piece of the section that very little real-world knowledge was considered:

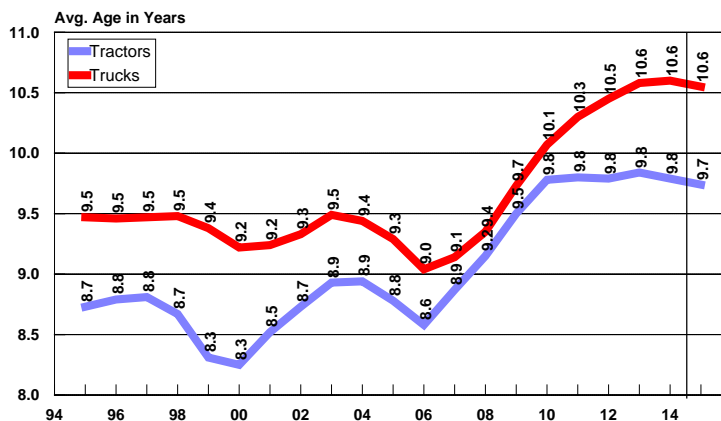
- Because shipping costs are so high, and until recently, fuel costs as well, there has been a concerted effort amongst shippers and truckers to rein in mileage. Owing to sharply higher transportation costs brought about by driver wages, oil prices and equipment costs, starting around 2006 there has been a concerted effort by shippers to increase freight density through package and product redesign.
- It is my experience that freight rates fall when there is too much capacity relative to freight demand. Changes in operating costs brought about by emissions mandates up or down don't change that math. As an example: Even as operating costs went up post 2007, because truckers bought so many trucks in 2006, freight rates fell. Similarly, and in regard to modal comments, what typically happens when trucking prices rise is that intermodal prices follow.
- A comment in paragraph 2 on page 132 was especially disappointing to read, considering that most Americans have seen wages stagnate over the past ~15 years. To paraphrase and take the inverse of the statement, if transportation costs more, consumers won't be able to buy as much. It would seem to me that making transportation cost more in the U.S. makes it more likely that goods are manufactured in countries with lower emissions standards and end up being transported even greater distances. Not only elitist, but irrational as well!

Once again, this brings us back to the notion that a successful emissions mandate is one that improves emissions and is close to operating cost neutral as possible.

Regarding the commentary on petroleum in section 5, it was obviously not only written prior to the recent decline in oil prices, but the comments suggest it was written prior to hydraulic fracturing revolutionizing domestic energy output starting around 2008. If "energy security" is a pressing concern (it was mentioned twice in a generally brief petroleum commentary), I reiterate my surprise that natural gas was not one of the technological avenues considered in this regulation.

U.S. Class 8 Population Model Outputs: Average Age, TOTAL Population

1995 - 2015



ACT Research Co., LLC. Copyright 2015

Regarding the commentary on the healthy benefits of regulation (Tables 49 and 50), there were no mentions of the purpose of the discount rate, or why 3% and 7% were chosen. While one would assume the 3% and 7% choices were to represent government and business related cost adjustments, this is certainly not clear from the reading.

4.3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

Belzowski

- For Fleet Turnover Effects, the 2007 rule was designed so that fleets had to be in compliance by 2010. The graph for this section should show more updated info on sales to see the effect of the rule during and after its implementation in order to see the total effects of the rule on sales.
- For Human Health Effects, Table 52 is confusing. What does an 11 mean? \$11 dollars annually?
- For Incremental Weight Effects: “Additional weight of new vehicle technologies could partially offset the fuel efficiency gains from the new technology.” Doesn’t the improved fuel economy that the new technologies boast of include the weight of the technology itself? Doesn’t the fuel economy of the hybrid system of the Prius assume a certain increase in weight?

Bezdek

No: Much more research and effort is required here. See my comments above and below.

Numerous indirect effects and unintended consequences associated with regulations designed to reduce fuel consumption in the trucking sector can be important. For example, researchers must consider the following effects: Rate of replacement of older vehicles (fleet turnover impacts), increased ton-miles shipped due to the lower cost of shipping (rebound effect), purchasing one class of vehicle rather than another in response to a regulatory change (vehicle class shifting), environmental co-benefits and costs, congestion, safety, and incremental weight impacts. The report mentions these, but does a very poor job of rigorous analysis and evaluation. This needs to be remedied.

It is often (but not always) the case that fuel efficiency improvements result in reductions of other pollutants as well. For example, new NO_x and PM standards may require additional fuel use and reduce vehicle fuel efficiency. It is more likely that reduced fuel consumption through fuel efficiency technologies in MD/HD vehicles will reduce emissions of criteria pollutants. Thus, efficiency improvements achieved by improved aerodynamics, tire rolling resistance, and weight reductions will translate into lower tailpipe emissions as well. Nevertheless, as discussed below, it cannot simply be assumed (as the draft report apparently does) that fuel efficiency regulations will automatically result in reductions of other pollutants as well.

New regulations designed to increase the fuel efficiency of MD/HD vehicles must also consider potential impacts on vehicle and highway safety. The safety impacts could be of several types. First, new technologies may have specific safety issues associated with them. For example, hybridization will introduce high-voltage electrical equipment into trucks, and operators, service mechanics, and emergency personnel will thus need to be educated about appropriate handling of this equipment. Second, as discussed, the rebound effect may increase overall truck traffic on the road, thereby leading to potentially higher incidences of accidents. Third,

some technologies and/or approaches to improving fuel efficiency may actually lead to a safer highway system. Examples include speed reductions, improved driver training, and use of side fairings which may reduce hazards to other vehicles in inclement weather. Fourth, if new technologies diminish the performance of vehicles (e.g., decreased acceleration times), negative safety impacts could occur. Finally, if new technologies or regulations have the effect of increasing payload capacity for trucks, fewer trucks may be in operation, potentially resulting in safety benefits. A detailed assessment is needed on these and related safety aspects – and on the specific regulations, and should be included in the draft report.

Detailed Comments on Section 5

P. 131, ¶ 5: “The issue of how new fuel efficient and emission reduction technologies and regulations will affect new vehicle prices and operating costs -- and the impact on fleet turnover from those cost effects -- is an area that needs further analysis.”

Agreed. But what does this imply for the whole NHTSA project?

P. 132, ¶ 2: “If investment in new technology is seen as cost effective and lowers operating costs,.....”

If this is so, then why is a regulation needed? Maybe, an outreach and information dissemination program would suffice, would be less intrusive, and would be much more cost effective.

P. 132, ¶ 4: “The implementation of technologies to improve fuel efficiency and reduce emissions can result in environmental co-benefits.”

Yes they can, but not necessarily – as noted above. This discussion is confusing and may be simply incorrect. These are regulations to increase vehicle fuel efficiency and are not designed to affect criteria pollutants. Have these benefits already been attributed to the environmental regulations specifically targeting them? Is there a danger of double counting here? EPA has a nasty habit of double counting (sometimes triple counting) environmental benefits in different air and water regulations. NHTSA must avoid such pitfalls if it is to retain its credibility.

P. 132: Rebound effect

It should be noted that the rebound effect may increase overall truck traffic on the road, thereby leading to potentially higher incidences of accidents. Has this, or will it be taken into account?

Also, to the extent the regulation extends beyond the private cost-effective point, the rebound effect will be reversed. This should also be discussed.

P. 132, ¶ 4: “In the 2014-2018 heavy-duty fuel efficiency program, NHTSA chose a rebound effect for single-unit trucks of 15%. For combination tractors, a rebound effect of 5% was chosen. NHTSA applied the light-duty vehicle rebound effect of 10% to the Class 2b&3 trucks.”

As discussed above, in MD/HD trucking, the “rebound” is a more complex phenomenon and has been studied less than the light-duty vehicle effect. Thus, it may not be valid to apply the light-duty rebound estimates here.

P. 133, ¶ 1: “For the purposes of this report/analysis, we present PM-related benefit per ton estimates as a means of monetizing the criteria pollutant co-benefits in the absence of full-scale air quality modeling to capture the full array of co-benefits associated with the technologies.”

Once again, it sounds like Tetra-Tech may be mixing or mis-estimating the combined effects of separate pollution control technologies.

Point of Clarification

My point here is that potential double counting of environmental benefits resulting from different rules and regulations must be avoided. Fuel efficiency technologies can indeed reduce emissions and can result in various types of environmental co-benefits. However, some of these environmental benefits may result from other current, impending, or planned environmental regulations and should not be double (or triple) counted. That is, some of these benefits may be, at least in part, attributable to environmental regulations specifically targeting them.

This is an important point because in the past, EPA has been accused (sometimes appropriately, and sometimes not) of double counting environmental benefits in different air and water regulations. Tetra-Tech and NHTSA must avoid such pitfalls if they are to retain credibility.

P. 133, ¶ 1: “GHG impacts are monetized according to their effects on human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), property, agricultural productivity, and terrestrial and aquatic ecosystems. Atmospheric GHG concentration influences global temperature and sea level, which in turn affect many complex natural systems. The risks associated with increased GHG concentration include mortality changes, increased flood risk, and decreased productivity due to weather. These risks shown in Table 52 were monetized in the social cost of carbon by the U.S. Government Interagency Working Group on Social Cost of Carbon.”

This paragraph is not credible. There is no scientifically valid relationship between CO₂ and diarrhea, vector borne diseases, etc. CO₂ is necessary for life and for agricultural production, and increased CO₂ increases agricultural productivity. Similarly, there is no empirically proven impact of GHGs on global temperature. The “proof” comes from unvalidated models which are increasingly inaccurate. Remote Sensing System (RSS) data show that there has been no global temperature increase for more than 18 years, despite increasing GHG concentrations. Similar comments pertain to the relationship between GHGs and flood risk, mortality changes, etc.

The IWG SCC estimates in Table 52 of the draft report (which are 50 percent higher than the IWG SCC estimates derived only three years earlier) have been thoroughly discredited. Independent, peer-reviewed evaluation has concluded that the IWG SCC estimates are “useless for policy purposes.” Further, SCC estimates are not accepted by Congress and are being litigated in court and in the states. They are phantom numbers that cannot be used to justify MD/HD regulations.

P. 134, ¶ 2: “Energy security premiums reflect the vulnerability of the U.S. economy to oil supply shocks, price spikes, and import costs. Because energy costs affect all sectors of the economy, U.S. dependence on petroleum imports from potentially unstable sources can have far-reaching effects. Political unrest in the Middle East and price hikes exerted through the near-monopoly power of the Organization of Petroleum Exporting Countries (OPEC), for example, have resulted in high gasoline and diesel prices at the pump.”

This sounds like it could have been written during the “energy crises” of the 1970s. Shale technologies have vastly increased U.S. liquid fuels and natural gas production to the point where the U.S. is becoming the world’s energy superpower. World oil prices have decreased 50% over the past six months, and OPEC is in disarray. The discussion in this section should be revised to reflect recent research and 21st century energy realities. For example, MD/HD regulations that may make sense or be cost effective at oil prices of \$100/bbl. may not with oil at \$50/bbl.

Das

Major elements of the potential cost impacts associated with each of the indirect effects have been only been qualitatively discussed. A further research on how to quantify some of these effects would be useful.

Fillion

The report raised the right indirect issues and provides an overview discussion. Actual field data is required to discuss these issues more completely; how to gain such data could be the work of a future study. The cost-to-benefit table mentioned above needs to be included here or elsewhere in the report.

Small

The discussion on p. 130 of timing of purchases may be taken to imply that acceleration or deceleration of purchases are equally likely. Actually a decision to “delay purchase to get more efficient vehicles (“post-buy”)” is less likely than the opposite because if there had been market demand for those vehicles, they probably would have been produced. This is true unless there are inefficiencies in the vehicle manufacturing market that prevent manufacturers from converging on design changes that would have market demand.

Table 51: The columns in this table do not match in any obvious way the categories in the verbal discussion. Specifically:

(i) “Monopsony” in the table refers to the ability of the United States, as a large player in international oil markets, to influence the world price to its advantage. One effect of the US having monopsony power might be to counter-act the “near-monopoly power” of OPEC, although monopsony power may have an impact on world price even in the absence of such near-monopoly power. In addition, this component of the energy security premium can be viewed as reflecting high oil prices throughout the economy, not just for gasoline and diesel fuel as implied by the wording.

(ii) “Macroeconomic Disruption/Adjustment Costs” in the table refers mainly to the effects of price spikes on overall economic growth. These effects are the results of oil supply shocks from any cause, not just political unrest or OPEC. The point of including them as indirect costs is that they presumably become smaller when oil-based fuels become a smaller part of the economy.

Vieth

The answer to question 3.1 gets to the heart of the revisionist history presented in this section and problems with the concept of rebound, the lack of awareness with what has been happening in the energy sector over the past ~decade regarding rebound, and the lack of “back story” on the section on pollution costs that was lost without reading the 7 citations in that section. Again, some rationale behind the chosen discount rates would have been helpful.

Given there were only a couple of paragraphs each tackling the complex subjects of congestion and incremental weight effects, those s

4.4 General Comments

4.4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Belzowski

- I have a mixed view about this report. On the one hand it tries and succeeds for the most part in modeling a very complex relationship among very diverse components of new vehicle technology (production overhead et al). Yet, I see some major issues related to the need for a conclusion and executive summary that discusses the results of the analyses, as well as the need for a clearer description of how the models were assembled and how the graphs are to be interpreted.
- Table 1 is full of abbreviations that are not noted on the abbreviations section. These abbreviations need to be added to the abbreviations section.

Bezdek

Organization is acceptable; readability and clarity could be improved. Examples and real-life experiences would help a lot. So also would recognition and incorporation of recent research in various relevant areas, a more comprehensive literature review, and the inclusion of relevant peer-reviewed research.

Das

Overall, the report is well-organized. Since the report is based on a review of extensive literature research, an appropriate discussion of underlying assumptions would strengthen the report quality.

Fillion

The organization, readability and clarity of this report is good. The report will be a valuable resource for both the expert and non-expert in the field of fuel economy improvements. For the expert the report puts in one place useful information that the expert could reference in their own work. For the non-expert the content of the report and the reference literature will allow the reader to become highly conversant in the subject in a relatively short amount of time.

Small

Overall the organization is transparent and the text clear, except where noted.

p. 131, experience from 2007 standards: "The peak [in Class 8 Truck Sales in 2006] corresponds to the incremental cost increase for the new standard (around \$10,000 for the 2007 standards)." Presumably this means that the peak coincides with the onset of the new standard, and thus might plausibly be caused by the associated cost of around \$10,000 per vehicle.

Vieth

The reports were readable and the organization of the supporting documentation was consistent throughout. So, they are fine as is. However, as the question was asked, following are a couple of thoughts:

The layout of the document was arranged by technology, rather than by vehicle type. This made the reading of the documentation, in this reviewer's opinion, more challenging as more flipping through the material was

required to look at the technologies as they impacted the light, medium, and heavy-duty market segments separately.

To that end, because the buyers, vocations, mileage, speeds, etc. are so different when analyzing the different markets, it is this reviewer's opinion that the reports would have been more informative had they been segmented by duty.

4.4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

Belzowski

- P.1 "Incremental retail prices are evaluated relative to the prices of the specific baseline technologies that would otherwise be used in the vehicles if the fuel efficiency and emissions reduction technologies were not implemented." Does this mean they are subtracting the cost of the current (specific baseline technologies) from the cost of new technologies with the resulting cost for that component being part of the "incremental retail price?"
- The intro to the report needs to spend more time describing the market in order for the reader to understand the impact of these technologies on manufacturers and suppliers. How big is this market in the US? How big is it globally? Is the report focusing on the US or the global market? This is very important because it will affect the investment global manufacturer and supplier companies will put into developing new technologies. Also, a large number of manufacturers and suppliers fighting over relatively small volumes is a disincentive to invest in this market. So understanding the potential volume in this market is important.
- Are these technologies that are estimated based on the number of new trucks sold per year or are there aftermarket implications? If a technology can be installed in the aftermarket, then potential volumes increase dramatically. If they cannot, then volumes are much lower.

Bezdek

No. Much additional information, research, and data are required – as discussed in my comments.

Das

In most parts, the information provided in the report is limited to some extent in terms of underlying assumptions. Values selected for incremental prices of various technologies are most cases judgmental, without providing any detailed supporting explanation behind the selection of a particular reference.

Fillion

The cost data is the area where both the expert and non-expert will gain useful reference information which is the primary strength of the report.

Small

p. 15: Step e in the example on p. 15 contains an unexplained equation, as well as a grammatically problematic sentence: "A power function formula is used estimate the initial years." Apparently this means that the transition between the short term multiplier (1 year) and the long-term multiplier (5 years) is a gradual one described by this formula. But no justification is given for such an equation, nor an indication of how the exponent in the formula is chosen. I infer that it is chosen so that after 5 years, the short-term

multiplier (1.39) multiplied by the power function equals the long-term multiplier (1.29); but I can't make the math work out to get the numbers shown.

p. 15: Steps d and g-j of the example introduce "Newness", a quantity defined nowhere in the report. It is said to be derived from Tables 2-4, but those tables do not contain any entry called "Newness". Perhaps it refers to the result of applying the learning rates of Table 4 to a given number of years?

Figures 1-91: These figures, showing total incremental price as a function of cumulative volume, are each labeled with an equation, but there is no indication how it is derived.

The text might address whether there is significant potential for inter-modal shifts between trucking and air freight. If so, such shifts might have an effect on economy-wide fuel use opposite to that of shifts between trucking and rail freight.

p. 136 note 22: The reference cited is a secondary one, i.e. not the original source of the statement. The statement attributed to "the NAS committee" actually occurs in the committee's own report, namely the National Research Council report of Reference 54, p. 153. This committee would be more properly described as a National Research Council committee rather than an NAS committee. (The National Research Council is operated jointly by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.) This authorship is correctly indicated in the citation to Reference 54 (Appendix A) as well as the list of references in Section 6.

Vieth

As stated in the preamble to the Peer Review Charge questions, it is difficult to examine the value of any technology without an understanding of the benefits of the technology to the desired goal of the regulation.

And as the answers to questions 1, 2, and 3 suggest, there was a decided lack of rigor found in both the incremental and life cycle cost sections, to include a lack of real-world pricing when applicable, pricing references that were not always apples-to-apples, a lack of documentation with regard to the life-cycle cost section as well as inconsistent cost estimates (US\$ versus %). Finally, there were a number of subject headers under section 5 that suggest the analysis was "dialed in": The conclusions in the history portion of the indirect effect section were inaccurate, and the commentary on petroleum was accurate in 2009, but requires some updating to reflect changes in oil sourcing that have occurred.

What is needed?

In term of the costing section, a detailed review of each technology, to include the use of the phone and the internet where products are actually available in the market. See previous comments on tires.

For the life cycle cost section, we could start with the definition of "end of first-owner life." As mentioned, a consistent dollars and cents based metric would provide more meaningful comparisons than "5%." Also, with so many n/a, TBD, and NNI responses, there were virtually no meaningful takeaways from this section. To that end, some discussion of methodology when prices were there, and some reasons why other cells were essentially left blank would be in order.

For section 5, I provided ACT Research data to show, definitively, that there was a prebuy ahead of EPA'07 in 2006 and even a very small prebuy action ahead of EPA'04 through the middle of 2002. I believe words like "probably" and phrases like "may be partially attributable" at a minimum need to be struck from the text, if not replaced by more accurate words like "absolutely" and phrases like "definitely contributed to."

4.4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

Belzowski

- The strongest parts are the attempts to model complex cost/price processes in the Incremental Cost Analysis, and the thoroughness of the secondary research that appears in the Appendices.
- The weakest parts are the lack of analysis of the results of the study at the beginning and end of the report, the lack of a detailed explanation of how the graphs in the Incremental Cost Analysis were created and an evaluation of the value or strength of each of the models, the missing data and timeliness of the data in the Lifecycle section, the lack of connectivity among the three sections in terms of modeling, and the need for more info about the Class 2b to Class 8 truck market.

Bezdek

The report contains much useful data and information. However, the applications to derive estimates and conclusions are rote and mechanistic, are often based on questionable assumptions, and require a lot of faith to believe.

Das

The problem of estimating incremental prices of medium- and heavy-duty vehicle fuel efficiency and emissions reduction technologies has been addressed really well using a cost-effective approach by drawing upon peer reviewed published studies and data. The report is well-organized in terms of an initial discussion of various cost elements by three major truck application types followed by actual price estimates including its breakdown based on a discussion of actual information source(s) in Appendix A.

Major weakest parts of the report is in Appendix A while discussing supporting data and references data used for a selection of the incremental price range of a technology. The selection rationale in most cases is not intuitive and a general discussion by each technology and truck application type if included in the main body of the report would be useful. It is very hard now for a reader to decipher the reasons behind the selection of specific incremental technology price range estimate.

Fillion

The cost data is the strongest part of the report while the discussions on the indirect effects is the weakest. The mention of the business issues regarding fleet turnover and rebound were good and raised the right discussion points. The effort to attribute a portion of the social cost of air pollution to trucks was not credible. The inclusion of a cost-to-benefit table as mentioned above is necessary in order to discuss the target technologies in a reasonable way.

Small

Strongest part: Extensive collection of engineering studies to estimate and document the costs of adding specific technologies.

Weakest parts: Lack of discussion of the accuracy of and uncertainty surrounding data from the cited references (see comments 1.4-2 and 1.4-3 [see 4.1.4 of this report]). Lack of rigorous basis for how incremental costs depend on cumulative production volume (see comments 1.4-2 and 1.4-3 [see 4.1.4 of this report]).

Vieth

If we were grading on volume, I would give the report an A. Considering this peer review group was tasked with only reading one portion of the report, our section was still a hefty 141 pages, complete with 120 page appendix. Unfortunately, “big” does not mean “good.”

This question comes-off as redundant to the second part of question 4.2. So, to paraphrase the paraphrasing:

Section 1 (and appendix): Inconsistent. Used very old studies for pricing guidance. In some cases, pricing was not apples to apples.

Section 4: The vast majority of the 37 tables had more n/a, TBD, and NNI, than answers. A brief paragraph per table regarding conclusions (or lack thereof) would have been helpful.

4.4.4 Please provide any other comments you may have on this report.**Belzowski**

None.

Bezdek

There may be more effective, less costly, and complementary approaches than vehicle fuel efficiency standards for reducing fuel consumption of MD/HDs, such as training truck drivers on best practices, adjusting size and weight restrictions on trucks, implementing market based instruments (e.g., fuel taxes), providing incentives for mode shifting, or developing intelligent vehicle and highway systems. This report should at least identify and discuss these.

There are a number of approaches for reducing fuel consumption in the trucking sector and there is evidence that several approaches -- particularly driver training and longer combination vehicles (LCVs) -- offer potential fuel savings for the trucking sector that rival the savings available from technology adoption for certain vehicle classes and/or types. The report could analyze these alternatives.

Notably, there are significant opportunities for savings in fuel, equipment, maintenance, and labor when drivers are trained properly. Research indicates that this could be one of the most cost-effective and best ways to reduce fuel consumption and improve the productivity of the MD/HD sector. Cases studies demonstrate potential fuel savings of 2 to 17 percent with appropriately trained drivers -- savings that compare very favorably with those resulting from many of the various technologies discussed in the draft report.

For example, regulations could encourage and incentivize the dissemination of information related to the relationship between driving behavior and fuel savings. One step in this direction could be to establish a curriculum and process for certifying fuel-saving driving techniques as part of commercial driver license certification and to regularly evaluate the effects of such a curriculum.

Research is also required to develop an approach that results in MD/HD fuel efficiency standards that are cost effective and that accurately represent the effects of fuel consumption reducing technologies. This work should recognize that regulations must fit into the engineering and development cycle of the industry and provide meaningful data to vehicle purchasers.

A pilot program is required to “test drive” the certification process and validate the regulatory instrument proof of concept. The program could be structured to obtain experience with certification testing, data

gathering, compiling, and reporting. An effort should be made to determine the accuracy and repeatability of all the test methods and simulation strategies that will be used with any proposed regulatory standards and a willingness to remedy problems that are identified. Data on fuel consumption could be obtained from several representative fleets of vehicles. Such research could provide a real world check on the effectiveness of the proposed regulatory design on the fuel consumption of MD/HD fleets in various parts of the marketplace, and in different regions of the country.

The economic merit of integrating different fuel-saving technologies will be an important consideration for operators and owners in choosing whether to implement these technologies. This is not adequately discussed in the draft report.

Since tractor-trailer trucks have relatively high fuel consumption, very high average vehicle miles traveled, and a large share of the total truck market, these should be targeted for fuel efficiency improvements and fuel consumption reductions. Similarly, large trucks account for about 80 percent of total truck fuel consumption. Accordingly, a given percentage reduction in such vehicle categories will save more fuel than a matching percent improvement in other vehicle categories. For example, the potential fuel savings in tractor-trailer trucks represents about half of the total possible fuel savings in all categories of MD/HD vehicles. Nevertheless, while it may be expedient to initially focus on those classes of vehicles with the largest fuel consumption, selectively regulating only certain vehicle classes could lead to unintended consequences and could compromise the intent of the regulation. Within vehicle classes, there may be certain subclasses of vehicles (e.g., fire trucks) that could be exempted from the regulation without creating market distortions. The draft report and any subsequent regulations based on it must incorporate these considerations.

Fuel consumption metrics should be calibrated to the task associated with a particular type of MD/HD vehicle and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo carrying capacity. Research needs to be conducted to determine whether a system of standards for full but lightly loaded (cubed-out) vehicles can be developed using only the LSFC metric or whether these vehicles need a different metric to accurately measure fuel efficiency without compromising the design of the vehicles. Research is also required to produce an approach that results in fuel efficiency standards that are cost effective and that accurately represent the effects of fuel consumption reducing technologies. Proposed regulations should fit into the engineering and development cycle of the industry and provide meaningful data to vehicle purchasers. The draft report should at least discuss these issues.

As discussed, to the extent that regulations alter the number of shipments and VMT, there will be safety and congestion impacts. A more detailed assessment of these impacts is needed based on the type of regulation discussed in the draft report and that may be implemented by NHTSA.

The technology packages that result in the fuel consumption reduction for each application have anticipated costs. These costs were estimated assuming that the technologies will be produced at large enough volumes to achieve economies of scale in the relevant time frames. Eventually, costs versus benefits will have to be estimated, and there are several ways to do this. One measure, dollars per percent fuel saved, is the cost of the technology package divided by the percent reduction in fuel consumption. Another measure, dollars per gallon saved per year, accounts for the fact that some vehicles are normally driven more miles than others and estimates how much it costs to save one gallon of fuel each year for the life of the vehicle by adopting the relevant technology. A third measure, "breakeven" fuel price, represents the fuel price that would make the present discounted value of the fuel savings equal to the total costs of the technology package applied to the vehicle class. However, the breakeven fuel price may not necessarily reflect how vehicle buyers would evaluate technologies. Because vehicle buyers often do not plan to own the vehicle for a full life, they may use a different discount rate, and they would need to consider operation and maintenance costs, which are

excluded from the estimates. However, a lifetime breakeven price is a useful metric for considering both the private and the societal costs and benefits of regulation.

Although incomplete, these measures indicate the differences in economic viability of the various technology options in the draft report for the indicated vehicle classes. However, breakeven prices are calculated assuming all the technologies are applied as a package whereas, in fact, individual fuel-saving technologies applied in a given vehicle class may face much lower or much higher breakeven values than indicated by aggregate figures. While detailed analysis of this issue may be outside of the scope of the draft report, it is important and should at least be mentioned.

There is an inherent conflict between the need to set a uniform test cycle for regulatory purposes and existing industry practices of seeking to minimize fuel consumption of MD/HD vehicles designed for specific routes that may include grades, loads, work tasks, or speeds inconsistent with the regulatory test cycle. This indicates the critical importance of achieving consistency between certification values and real-world results, in order to avoid driving decisions that degrade rather than improve real-world fuel consumption. Regulations can lead to unintended consequences, either because the variability of tasks within a vehicle class is not adequately dealt with or because regulations may lead to distortions between classes in the costs of accomplishing similar tasks. There is little evidence that the draft report has adequately addressed these issues.

More fundamentally, fuel consumption by MD/HD vehicles represents nearly 30 percent of total U.S. liquid transportation fuels and has increased more rapidly -- in both absolute and percentage terms -- than consumption by other sectors, and these trends are forecast to continue. At the same time, over the past two decades MD/HD vehicle fuel efficiency has been increasing by about one percent per year without vehicle regulations. This critical fact is not recognized in the draft report. A one percent annual compounded rate of change is, in the long run, nontrivial and, given the huge volume of fuel consumption is significant. Why has this been occurring in the absence of regulation? How might new MD/HD regulations change this annual rate of fuel efficiency increase? Would the presumed or estimated increase in this rate be worth the time, effort, costs, indirect effects, and unintended consequences of new MD/HD regulations? Might new regulations actually be counterproductive here? All these are important issues that need to be addressed.

Das

Additional comments by specific page number of the report have been included at the end of the report. [see section 5.0 *Additional Comments Provided*]

Fillion

The report is a good compilation of the relevant target technologies for truck fuel improvements and a good estimate of their cost. With the inclusion of a cost-to-benefit table a discussion something like the following could take place.

In order to reduce CO₂ emissions, the government is considering increasing fuel economy standards for trucks. In order to improve profitability, truck companies are considering new technologies to increase the fuel economy of their fleets. Improving truck fleet fuel economy is a shared goal for the government and the truck industry. It is recommended that this shared goal be leverage in the rule making process. Today each truck company has an internal policy regarding the payback required to deploy new technology. For example, the policy might be a 1 year payback, at \$4 a gallon for fuel, to deploy a new fuel economy improvement technology. In order to drive the truck companies to increase their take up rate for new fuel economy technologies the payback policy needs to be changed. If the government could devise a regulation that caused the payback policy to be 3 years at \$6 per gallon fuel cost, for example, there would be a significant

increase in the take up rate for new technologies to improve fuel economy and thus reduce CO2 emissions. The government- industry debate could simply be a negotiation of an acceptable payback period for the desired level CO2 reduction.

Complementary to the cost-to-benefit table, it would be useful to have an environmental life cycle study for the target technologies (in addition to maintenance cycle of this report). In this study, the CO2 generated to create and deploy a target technology would be measured and compared to the CO2 saved through its use. Those target technologies that have a net positive CO2 reduction would also have a specific economic payback period. Thus a correlation table could be generated that linked CO2 reduction to a payback period at various fuel costs. Using this approach it is likely that the point would be found where the increased CO2 required to deploy certain target technologies would not have a net CO2 reduction, and thus be counterproductive. It appears that Tetra Tech has sufficient data to make such a correlation study and they should be charged to do so. For truck fleets there is a strong correlation between net cost savings for new fuel economy improvements and net CO2 reduction; intuition suggests that there should be a wise way to leverage this government industry shared goal in the rule making process.

Small

p. 132, “Ton-Miles Traveled vs. Rebound”. This discussion is accurate and valuable. It is worth noting here a difference between the rebound effect for trucks and that for cars. With cars, it is reasonable to take vehicle-miles as the variable measuring quantity demanded, which will respond to changes in cost per vehicle-mile. With trucks, cargo ton-miles is the relevant demand-related quantity, and it may respond in a more complex way to changes in cost per truck-mile, since trucking firms have several options for adjusting the mix of vehicles they use in reaction to particular regulatory-induced changes in vehicle costs and characteristics. In particular, if changes in truck design reduce the payload, they might increase rather than reduce price per ton-mile and this would tend to offset the “rebound effect”.

Wording, typos, etc:

p. 130: “rebuild old vehicles and extend its life”

p. 133: “complexity scalability”??

Vieth

I prefaced my comments stating that the best outcomes are those derived from the harvesting of the lowest hanging fruit, where there is buy-in from the most important constituency, truck buyers. The rapid adoption of CAFE’14 compliant vehicles, which deliver bang-for-the-buck operating cost improvements, are a great example of the intersection of goals of regulators and truckers. What we saw ahead of EPA’06 provides an inverse example.

Importantly, and to that end, technology cost impacts are often non-linear. In this report, many of the methodologies and projections are based on linear models and presumed effects. Simple and easy to understand, linear models often work well, especially with small delta events. Major costs moves on the other hand, especially when accompanied by no avenue to payback for equipment buyers, or mandate five-figure disruptive technologies, can have non-linear outcomes with exponentially adverse impacts. A technology that carries a big five-figure cost will trigger a distortive prebuy and cause truckers to maintain existing equipment longer, thereby defeating environmental objectives.

4.5 Overall Recommendation

4.5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable? Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

Belzowski

I think this report is acceptable with revisions. Whether NHTSA, EGR, and the authors consider them major revisions is up to them. I refer to my listing of the weaknesses of the report for justification. From the weaknesses section: The weakest parts are the lack of analysis of the results of the study at the beginning and end of the report, the lack of a detailed explanation of how the graphs in the Incremental Cost Analysis were created and an evaluation of the value or strength of each of the models, the missing data and timeliness of the data in the Lifecycle section, the lack of connectivity among the three sections in terms of modeling, and the need for more info about the Class 2b to Class 8 truck market.

Bezdek

The report is acceptable with major revisions, as discussed in my comments.

Das

The report is acceptable as is with the exception of quantification of life cycle cost elements and most indirect cost categories necessary for the follow-on life cycle cost analysis. Since the report draws upon reported incremental prices of published studies and data instead of significantly more expensive teardown analysis, some sort of validation in form of case studies and/or available price data for a few of the commercially available technologies would have strengthened the results presented. A summary discussion of incremental price estimates by technology and truck application type in the main body of the report would be useful.

Fillion

The cost section is acceptable as is.

The Life Cycle section needs its nomenclature changed to Vehicle Life Maintenance. The technical data is acceptable as is.

For the Indirect Cost section, the human health and environmental co-benefits portion should be deleted.

The inclusion of a cost-to-benefit table, preferably in its own section, needs to be included.

It would also be helpful to have a CO₂ based environment life cycle for each of the targeted technologies. The study would be useful - even if done at a low detail level in order to avoid excessive cost and time delays.

With the above changes the report is classified as acceptable with minor revisions.

Small

(3) Acceptable with major revisions. The major revision is to fully assess the degree of confidence that can be placed in the incremental cost estimates. This requires a deeper discussion of selected technologies, choosing those most likely to be significant in responses to fuel efficiency standards. It also requires analysis of how a most likely value can be derived from the full set of estimates available, not just the highest and

lowest estimate. See comments 1.4-2 and 1.4-3 [see 4.1.4 of this report]. Minor revisions are needed to clarify various unexplained derivations, as detailed in other comments in this peer review.

Vieth

Based upon my review, I would assign a grade of 3 to the report. While the structure is adequate, there are significant shortfalls in execution. A listing of those shortfalls follows:

The technology cost estimate section needs to be gone through with a fine-toothed comb to clean-up inaccuracies, and for those products that are available today, pricing should be accessed from vendors, either by phone or over the internet.

For the life cycle cost section, there needs to be better documentation of how maintenance, replacement, and residual values were derived (or not).

There needs to be a good look through the document to clean up ambiguities:

Table 2: Define short and long term

Tables 49-50: Why those discount rates

The parts of section 5 regarding energy, were written before North America became a juggernaut in global energy markets

The portion of the report discussing the history of regulatory impacts in regard to impacting heavy truck demand, entitled Fleet Turnover Effects, soft sells the impact of regulatory costs on demand and does not address the adverse non-linear impacts of high-cost regulations.

5.0 ADDITIONAL REVIEWER COMMENTS

This section presents reviewer comments that were not provided in response to a charge question (i.e., presents all comments not already provided in Section 4).

Belzowski

Introduction

Overall, I admire this attempt to investigate the total costs involved in developing, manufacturing, and selling these new technologies. It is a difficult task because of the uncertainty surrounding the development of many of these technologies for the truck market.

Estimating the prices/costs connected with direct costs, production overhead, corporate overhead, selling and dealer support, and net income is ambitious, and I commend the authors on tackling such a complex topic. The ways the authors use to try to account for all of these elements of the total costs analysis are very interesting. I wish I could comment on how to improve them, but this is outside my expertise.

One area of concern has to do with the audience for this report. The report tries to simplify the complex analyses that were devised to generate estimates for each technology, but I think the resulting document still is difficult to understand. This is always a challenge for a technical report. How does one make the complex results understandable to the people who want to use the results for developing policy? One way is to summarize the results in an executive summary, especially since many people will not read the full text either because of time or because of its complexity.

Bezdek

1. Introduction

Detailed Comments on Introduction

P. 1, ¶ 1: “This report examines the costs of implementation, nominally in 2011 U.S. dollars.”

This wording is confusing and incorrect. By definition, “nominal dollars” are not inflation-adjusted and refer to the dollars of the year in question. The correct terminology is “constant 2011 dollars” and the report should reflect this.

P. 1, ¶ 2: “Incremental retail prices are evaluated relative to the prices of the specific baseline technologies that would otherwise be used in the vehicles if the fuel efficiency and emissions reduction technologies were not implemented. These prices include the technology components as well as their installation and incorporation in the vehicle. Incremental retail prices account for all costs associated with the manufacturers and suppliers’ production and sale of the technologies to the retail purchaser.”

This statement is questionable. It is very difficult to precisely estimate future retail prices that would occur if the new standards were not implemented.

P. 1, ¶ 4: “Indirect economics effects encompass the broader impacts not captured through incremental and life cycle costs.”

The report’s conception of indirect economics appears to be somewhat flexible in different sections of the report. It should also be distinguished from the conventional economic direct and indirect effects that are derived via interindustry input-output analyses.

Point of Clarification

My major point here is that most analysts when they see the phrase “indirect economic impacts” think immediately of those derived using standard economic input-output (I-O) analysis.

I-O analysis has been widely used for the past half-century to estimate the total (direct, indirect, and induced) impacts created by an activity, expenditure, or program

- Direct impacts are those created directly in the specific activity or process
- Indirect impacts are those created throughout the required inter-industry supply chain
- Induced impacts are those created in supporting or peripheral activities; e.g., in a restaurant across the street from a vehicle manufacturing plant
- Total impacts are the sum of all of the impacts created
- For simplicity, analyses sometimes include induced impacts in the indirect category

The total (direct, indirect, and induced) impacts concept is the accepted methodology widely used in studies of this nature and in the peer-reviewed literature.

Tetra-Tech in the study is using a different definition of indirect economic impacts. This is O.K., but Tetra-Tech should be careful to precisely define what they are talking about to distinguish their concept from the standard, accepted definition of indirect effects. Such a discussion will also add credibility to the report, since it will indicate that Tetra-Tech is aware of the standard I-O concepts.

2. Fuel Efficiency and Emissions Reduction Technologies

Detailed Comments on Section 2

P. 2, ¶ 1: “At present, vehicles in this category operate primarily with diesel engines, though improving gasoline engine technologies may encourage the increased use of gasoline engines in the Vocational category.”

While diesel engines can offer substantial fuel efficiency advantages, it should be noted that the cost of meeting new emissions standards with gasoline engines is usually much less than with diesel engines. Diesel engines start with a significant cost disadvantage compared to gasoline engines, because of their greater strength (to withstand the high-cylinder pressures of compression ignition) and their far more sophisticated fuel systems. Diesel fuel systems have injection pressures of 1,600 to 3,000 bar, while even the expensive (by gasoline engine standards) GDI fuel systems require only 100 to 200 bar. Port injection systems for gasoline engines typically use injection pressures of only a few bar. The need to create and control extreme pressures has a major effect on diesel fuel system cost.

When the higher cost of diesel engines is added to the significantly higher cost of diesel emissions control after-treatment, there is a powerful market incentive to move toward gasoline engines, except where the durability of the diesel engine is required. In recent years, diesel engines have lost market penetration to gasoline engines in some classes of MD/HD vehicles. Studies also indicate that recent emissions regulations may be accelerating the trend toward gasoline engines in medium-duty trucks. Will this also be the case with MD/HD vehicles? The draft report should address this important issue.

Suggestive List of References That Could be Consulted

(These are meant to be indicative, not comprehensive)

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Das

1. p. 13 It is noted that the relative net income increases with increasing technology complexity – not found to be the case in Tables 5 thru 8. The net income share of incremental price was found to be the same in most cases and the transition from High 1 to High 2 Technology Complexity case caused a rather decrease in its share.
2. p. 17-20 (Table 10 & 11): The incremental price of Weight Reduction per unit mass savings is estimated to be the same for Vocational and Line Haul vehicle types. The underlying assumptions behind substitution materials discussed in Appendix C (Vehicle Simulation and Vehicle Technologies) by vehicle type are unclear. Estimates used from Appendix A based on various sources require a validation of underlying assumptions before selecting the appropriate value. It is preferred that the data validation be done in all technology cases.
3. p. 112: Life cycle costs – fuel savings are determined from SwRI are not being included here and thereby provides an incomplete picture of life cycle costs.
4. p. 118 -122: The battery replacement cost of \$455 doesn't seem to vary by truck type although power requirements are most likely to vary to some extent (p.118-119). Similarly, for hybrid electric vehicles on p. 120 and for Cab Insulation to Reduce A/C (p. 122).
5. p. 128: Resale value has been shown only in the case Class 8 6x2 Configuration
6. p. 34 & 35 : no incremental price difference between various truck classes (mainly for Class 2b&3 and Class 4-6) for Cylinder Deactivation, Stoichiometric GDI, Lean Burn GDI with SCR, Turbocharging & Downsizing, Engine Downsizing, Low Friction Engine Oil (D) & (G), Engine Friction Reduction (D) & (G), Air Conditioning Improvements, Cab Insulation Price, Low Resistance Tires, Low Friction Axles & Lubricants, ?
7. p. 99-101: Incremental prices for low resistance tires seems to be too low, particularly \$27-\$30 for Class 8 truck?
8. p. 54: Engine Friction Reduction – prices same for Class 8 & Class 4-6?
9. p. 130- 131: Fleet Turnover Effects as a part of life cycle costs component was limited to a discussion of issues associated with it without any available estimates from the literature.
10. E-1: When a large incremental price range is selected, e.g., \$7,200-\$30,200 for Class 8 Advanced Bottoming Cycle, the average price based on this wide range may be inappropriate. Further investigations in such cases may be necessary for the appropriate value range for consideration in the analysis.
11. p. E-41 – E- 42: Although same information sources indicating no difference in costs between Class 2b&3 Engine Friction Reduction (G) & (D), but a lower cost value was assumed in the latter case. Similar trend was also observed for Class 4-6 Engine Friction Reduction cases as well but in this case no cost difference between Class 4-6 & 8 (D) vehicle type.

12. E-46 – E-47: Difference in cost between (D) and (G) but the same information sources used do not explicitly provide this distinction.

13. E-59 – E-64: It is appropriate to include only those references used for deriving the cost range of hybrid electric vehicle for different types instead of listing the same references in all cases.

14. E-70 – E-75: No cost difference for Air Conditioning Improvements and Cab Insulation to Reduce A/C among three different vehicle types considered. The maxm. range value of \$500 used in this case doesn't appear to be from one of the listed sources.

15. E-93 – E-100: Same information sources used for all vehicle types of Improved Transmissions – but the highest cost range used for Class 8 vehicle type was based on the estimates for Pickup trucks.

16. E-103: Class 4-6 Dual Clutch Automatic – What's the selection basis for the higher end range value of \$3,600 although two of the sources identified to be \$15,000 instead?

Vieth

Before digging into the five questions that comprise the scope of this review, several comments are in order:

First, any objective measure of the technologies under review was obscured by the fact that this mandate was to review the cost of the technologies, but not the benefits of those technologies. To that end, the absence of any bang-for-the-buck capability essentially mooted higher level insights that could have been brought to bear regarding end user payback timing and the impact of that timing on the commercial vehicle demand cycle.

Second, while the costs of the technologies and the incremental manufacturing costs were estimated in detail across a matrix of manufacturing outputs, very little in the analysis considered the product's end users - truckers. The very short timeline of the 2004-2010 EPA regulatory push to clean up NOx and particulate matter suggests that end-user behavior has received the short shrift in the impact analysis of mandates. For a comparable progression of technologies and associated costs, European regulators took an additional three years to go from Euro 4 in 2005 to Euro 6 in 2014.

Since the end of the massive prebuy of equipment in 2006 ahead of EPA'07, there has been a meaningful increase in the chronological age of the total Class 8 fleet in the U.S., from 8.7 years in 2006 to 9.9 years at the end of 2014 (ACT Research data). Perhaps it is coincidental, rather than causal, but it is worth noting that since 2008, the point at which fleet age rose substantively, there has been virtually no change in the number, or rate, of heavy truck related fatalities on U.S. roadways following a long stretch of continuous improvement.

Third, and to the point mentioned above, regulations in the U.S. tend to be "stick," rather than "carrot" based. In the heavy-duty market, EPA'04 and EPA'07 are examples of mandates that raised the cost of vehicles with no usage-based payback for the end user. Adding insult to injury, truckers who were required to purchase technologies that provided no operational payback and raised maintenance costs were also taxed for the privilege of paying more (Federal Excise Tax [FET] + State). So, the tractor sleeper that in 2002 was an estimated \$95,000 + 20% tax (FET @ 12%, state @ ~8%) vehicle is, after EPA'04, '07, '10, Advanced On-Board Diagnostics (AOBD), and Corporate Average Fuel Economy (CAFÉ) '14 a nearly \$130,000 + 20% tax vehicle today. That jump in vehicle cost raised truckers' tax burden by \$7,000. While some of that higher cost is related to commodity costs, and certainly some increment for margin preservation on the part of the truck manufacturers (OEMs), it is not a stretch to suggest that the vast majority of the price increase and subsequent increase in the new truck buyer's tax burden is directly related to regulation. In a word, punitive.

While the desire for cleaner air is applauded, it seems to this reviewer that the objective should be to encourage truckers to buy new trucks, rather than to hold on to their old trucks longer. While it is recognized that different departments have different mandates and different authorities, getting Congress into the act could pay substantive dividends if cleaner air is the desired outcome: A phasing out of the 12% FET on new truck purchases, replaced with a revenue neutral (or even revenue positive) increase in diesel fuel tax, would reinforce the desired behavior by making new trucks more affordable to purchase and older trucks more expensive to operate.

Finally, of the 40 technology options offered, natural gas as an alternative, cleaner burning fuel did not crack the list as a technological solution. While not a chemist, and recognizing that natural gas is a carbon based fuel, it has nevertheless been this reviewer's assumption that natural gas was a cleaner alternative to diesel with half the carbon of diesel - at least at the molecular level. All the more shocking in the absence of a natural gas option was that Hybrid Electric Vehicles (HEVs) were a considered solution, especially with the knowledge that coal and natural gas will most often be the sources of electricity generation.

APPENDIX A

REVIEWER CURRICULUM VITAE/RESUMES



NAME	Bruce M. Belzowski
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RESEARCH AREAS	Bruce Belzowski has authored or co-authored research reports focusing on a variety of automotive topics including product development, manufacturer-supplier-dealer relations, globalization, information technology, knowledge management, and human resources. His current research topics include powertrain strategies and powertrain R&D, intelligent transportation systems (ITS), globalization of the automotive industry, and heavy truck safety technologies.
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**AWARDS/
HONORS** Flynn, M.S.; Belzowski, B.M. 1995. "Barriers to Automotive Structural Composites: Concerns, Competition, and Competence." University of Michigan Transportation Research Institute, Office for the Study of Automotive Transportation. 19 p. ESD Advanced Composites Conference and Exposition. 11th Annual. Proceedings. Ann Arbor, ESD, 1995. Pp. 517-534. **Best Paper Award** Sponsor: Automotive Composites Consortium/ Owens-Corning Fiberglas Corporation. UMTRI-88956

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Dr. Bezdek has served as Corporate Director, Corporate President and CEO, University Professor, Research Director in ERDA/DOE, Special Advisor on Energy in the Office of the Secretary of the Treasury, U.S. energy delegate to the European Community and to the North Atlantic Treaty Organization, and as a participant in the U.S. State Department AMPART program. He has served as a consultant to the White House, the Office of Al Gore, Federal and state government agencies, and various corporations and research organizations, including the National Science Foundation, NASA, DOE, DOD, EPA, IBM, Goldman Sachs, Raytheon, Lockheed Martin, J. P. Morgan Chase, Peabody Energy, Ontario Power Generation, Eastman Kodak, American Solar Energy Society, the Rockefeller Foundations, UN Environmental Program, Pew Charitable Trusts, Japan Atomic Energy Research Institute, National Energy Technology Laboratory, Electric Power Research Institute, Edison Electric Institute, National Coal Council, and Nuclear Energy Institute. During 2003/04, he served on the Federal Task Force charged with rebuilding the economy of Iraq. He is active with the National Research Council of the U.S. National Academies of Science (NAS), and served as a member of the joint NAS/Chinese Academy of Sciences Committee on U.S.-Chinese Energy Cooperation and on the NAS Committee on Fuel Economy of Medium and Heavy Duty Vehicles. During 2008, he presented energy briefings to the staffs of Senators Barack Obama, John McCain, and Hillary Clinton.

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SUJIT DAS

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Knoxville, Tennessee 37934

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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 2nd 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 clean energy manufacturing programs for the U.S. Department of Energy. Develop, manage and lead projects for the DOE Office of Vehicle Technologies and Advanced Manufacturing Office. Responsible for a total annual budget of more than \$750K consistently over the past several years and managing a team of 1-6 people per project depending on the project type. 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:

- Life Cycle Assessment of Aluminum Intensive Vehicles for the Aluminum Association
- Next generation materials with energy/emissions reduction potential in the U.S. industry for DOE Advanced Manufacturing Office
- Manufacturing process modeling of high temperature stationary fuel cell systems in the 350-400 kW power range for DOE Fuel Cell Technologies Program
- Life cycle modeling of alternative lightweight engine design options for the DOE Propulsion Materials Program
- 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 for DOE Office of Vehicle Technologies
- Material technology assessments related to Partnership for A New Generation of Vehicles (PNGV)/Freedom Cooperative Automotive Research (FreedomCAR)
- Potential of renewable energy technologies in rural Bangladesh
- 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/CHAPTERS PUBLISHED

Two book chapters published in "Advanced Composite Materials for Automotive Applications: Structural Integrity and Crashworthiness," Edited by Ahmed Elmarakbi, Univ. of Sunderland, UK and published by Wiley & Sons (Aug.'13)

Chapter 3: Low Cost Carbon Fibre for Automotive Applications (Part 1: Low Cost Carbon Fibre Development);

Chapter 17: Low Cost Carbon Fibre for Automotive Applications (Part 2: Applications, Performance and Cost Reduction Models)

"Recycling and Life Cycle Issues for Lightweight Vehicles," A Book Chapter in Materials, Design and Manufacturing for Lightweight Vehicles, edited by P.K. Mallick, Woodhead Publishing Limited, pp. 309-330, 2010

"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/PRESENTATIONS (Out of 60+ articles)

“Cost of Ownership and Well-to-Wheels Carbon Emissions/Oil Use of Alternative Fuels and Advanced Light-Duty Vehicle Technologies,” *Energy for Sustainable Development*, 17(2013), pp. 626-641

Served as one of the expert reviewers for the following three recent U.S. DOT/U.S. EPA reports
Mass Reduction for Light-Duty Vehicles for Model Years 2017-2025, EDAG/The George Washington University Report, Apr. 2012
Light-Duty Technology Cost Analysis Pilot Study, FEV Draft Report, Sept. 3, 2009
An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program, Lotus Engineering Inc., Mar. 2010

“Lightweighting Opportunities in the Global Automotive Industry,” invited presentation at the 2011 International Automotive Lightweight Materials Development Forum, held in Chongqing, China, on Mar. 24-25, '11. (Also at the 12th IUMRS International Conference on Advanced Materials, held in Qingdao, China on Sept. 22-28, 2013)

"Importance of Economic Viability Assessment of Automotive Lightweight Materials" invited presentation at the 3rd Annual Advanced Lightweight Materials for Vehicles conference held on Aug. 11-12, '10, Detroit, MI.

“Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints,” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2168, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 136-145.

“Reducing GHG Emissions in the United States’ Transportation Sector” *Energy for Sustainable Development*, 15 (2011) 117–136, May 11.

“Life Cycle Assessment of Carbon Fiber-Reinforced Polymer Composites,” *Intl. Journal of Life Cycle Assessment*, Volume 16, Issue 3, pp. 268-282, 2011

“Battle Green,” an interview article published in *American Metal Market*, Oct. 2010, pp. 36-40.

“Shedding Pounds On a Magnesium Diet,” *Automotive Engg. International*, Apr. 6, 2010, pp. 34-36, interview article by Steven Ashley.

“Analysis of Fuel Ethanol Transportation Activity and Potential Distribution Constraints,” *Transportation Research Record: Journal of the Transportation Research Board*, No. 2168, Transportation Research Board of the National Academies, Washington, DC, 2010, pp. 136-145.

“Low-Carbon Fuel Standard – Status and analytic issues,” *Energy Policy*, vol. 38, No.1, Jan. 2010, pp. 580-591.

“Importance of Economic Viability Assessment of Automotive Lightweight Materials,” invited presentation at the 3rd Annual Advanced Lightweight Materials for Vehicles,” held in Detroit, MI on Aug. 11-12, 2010.

“A Comparative Life Cycle Assessment of Magnesium Front End Parts,” SAE Paper No. 2010-01-0275, Society of Automotive Engineers, Warrendale, PA.

“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.

AWARDS & PROFESSIONAL ACTIVITIES

Awarded 2004 Journal of Metals Best Paper by the Mineral, Metals, and Materials Society (TMS)

Chair of Society of Automotive Engineering (SAE) Sustainable Program Development Committee (2013-2014)

Member of Transportation Research Board (TRB) Committees (2008- Present)
Transportation Economics
Alternative Transportation Fuels and Technologies

Invited Speaker on the Life Cycle Assessment of Materials by Beijing University of Technology, China
Conference Session Organizers for SAE and TRB

Peer Reviewer for Several Energy and Environmental Related Journals

Resume for John Fillion

John Fillion received his Bachelor of Science in Chemical Engineering from the University of Toledo, his Master of Arts in Management from Central Michigan University, and his Master of Science in Materials Engineering from the University of Dayton. He joined Chrysler in 1978 as a Materials Development Engineer and developed applications for elastomers and plastics in the areas of powertrain, chassis, exterior, and interior components.

In 1988 John Fillion was appointed to the position of Supervisor of Interior Plastics and Soft Trim Materials. This position was responsible for the Material, Process, and Performance Standards of all interior decorative materials used for Chrysler products. In 1992 he was appointed to the position of Senior Manager of Organic Materials Engineering. This department was responsible for the Materials, Process, and Performance Standards for elastomers, fluids, glass and plastics applied to Chrysler vehicles. In addition the position was responsible for leading Chrysler composite activities associated with the Automotive Composite Consortium (ACC) – a consortium of Ford, GM, and Chrysler. John Fillion served as the Chairman of the ACC twice.

In 1993 John Fillion, as a charter director, assisted in the formation of United States Automotive Materials Partnership (USAMP), a consortium of Ford, GM, and Chrysler that directed materials research for light weight vehicles, funded in part by the Department of Energy (DOE). He served as Chairman of USAMP six times.

In 1996 he was appointed Senior Manager of Body Materials Engineering which was responsible for the Materials, Process, and Performance Standards for sheet metal, welding, corrosion, adhesives, and paint. The position was also responsible for directing Chrysler day to day materials development activities with the Auto Steel Partnership (A/SP) while he continued his role with USAMP. Through these dual roles he redirected A/SP efforts to pursue research projects with USAMP using DOE funding.

In 2001 John Fillion was appointed Senior Manager of Powertrain and Chassis Materials Engineering which was responsible for Materials, Process, and Performance Standards for castings, forgings, powder metal, heat treatment, and the materials characterization testing laboratories. During this time he continued his role as chairman of USAMP increasing the diversification of the consortium research portfolio which saw increases in the funding for steel and magnesium materials while continuing funding for aluminum and composites.

At the end of 2007 John Fillion retired from Chrysler.

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EDUCATION

B.S., A.B. University of Rochester, 1968, Physics, Mathematics
 M.A. University of California, Berkeley, 1972, Physics
 Ph.D. University of California, Berkeley, 1976, Economics

ACADEMIC AND PROFESSIONAL POSITIONS HELD

2006- Professor Emeritus of Economics, University of California at Irvine
 1986-2005 Professor of Economics, University of California at Irvine
 1983-86 Associate Professor of Economics, University of California at Irvine
 1976-83 Assistant Professor of Economics, Princeton University
 1972 Intern, President's Council on Environmental Quality
 1971-76 Teaching and Research Assistant positions, University of California, Berkeley
 1969-70 Research Assistant, Dept. of Environmental Medicine, Johns Hopkins University

ADMINISTRATIVE POSITIONS HELD

2001-03 Vice Chair, Department of Economics, UC Irvine
 1992-95 Chair, Department of Economics, UC Irvine
 1986-92 Associate Dean for Graduate Studies, School of Social Sciences, UC-Irvine
 (Acting Dean, various periods, 1988-92)

FIELDS OF SPECIALIZATION

Urban Economics, Transportation Economics, Discrete-Choice Econometrics, Environmental Economics

VISITING POSITIONS

Nonresident Fellow, Resources for the Future, Washington, D.C., 2010-
 Professor II (10%), Molde University College (Norway), 2007-2012
 Visiting Professor, Universitat Autònoma de Barcelona, Oct 2008
 Visiting Patterson Scholar, Northwestern University, Apr.-June 2004
 Gilbert White Fellow, Resources for the Future, Washington, D.C. 1999-2000
 Visiting Professor, Katholieke Universiteit Leuven, Belgium, May 2000
 Visiting Professor, Harvard University, 1991-92
 Visiting resident: Boston College (Jan.-June 1992), Tel Aviv University (March-April 1990)
 Research Associate, Brookings Institution, 1978-79

EDITORIAL POSITIONS

Editorial Boards: *Journal of Urban Economics* (since 1989); *Journal of Transport Economics and Policy* (since 1995); *Transportation Research, Part B: Methodological* (since 2008); *Economics of Transportation* (founding member, since 2011).
 Associate Editor, *Transportation Research, Part B: Methodological*, 2003-07
 North American co-editor, *Urban Studies*, 1992-97
 Book series co-editor, *Transp. Research, Economics and Policy*, Kluwer Academic Pub., 1993-2003
 Past editorial boards: *Journal of Economic Geography*, 1999-2003 (founding member); *Urban Studies* (1997-2003); *Regional Science and Urban Economics* (1987-2010); *Transportation* (1993-2010).

PROFESSIONAL AFFILIATIONS & AWARDS

Founding President, International Transportation Economics Association, 2011-14
 Excellence in Refereeing Award, *American Economic Review*, 2009, 2011
 Faculty Achievement Award (for research, teaching, and service), Univ. of Calif.-Irvine, 2007
 Fellow, Regional Science Association International, 2006
 Visiting Patterson Scholar, Northwestern University, 2004
 Distinguished Transportation Research Award, Transportation Research Forum, 2004
 Distinguished Member Award, Transp'n & Public Utilities Group, American Economic Association, 1999
 Gilbert White Fellow, Resources for the Future, 1999-2000

Special issue of *Journal of Urban Economics* entitled *Essays in Honor of Kenneth A. Small*, vol. 62, 2007

Listed in: Edward Elgar, *Who's Who in Economics*; Gale Research, *Contemporary Authors*; Marquis *Who's Who in the World*, *Who's Who in America*, *Who's Who in Science and Engineering*, *Who's Who in Finance and Industry*; Academic Keys *Who's Who in Social Sciences Higher Education*.

Professional memberships: American Economic Assoc.; Association of Environmental and Resource Economists; International Association for Travel Behaviour Research; International Transportation Economics Association (member, Executive Committee); Regional Science Association.

Other affiliations:

Transportation Center, University of California (system-wide); Institute of Transportation Studies, UC-Irvine; Institute of Mathematical Behavioral Sciences, UC-Irvine

REFEREEING, CONSULTING, AND PUBLIC SERVICE ACTIVITIES**Advisory Groups:** (since 1991)

Advisory Committee, Center for Energy Economics and Policy, Resources for the Future, 2012-.
 Ridership Technical Advisory Panel, California High-Speed Rail Authority, 2010-.
 Advisory Board, GRACE project (Generalisation of Research on Accounts and Cost Estimation), funded by European Union through Univ. of Leeds, 2005-07.
 Advisory Board, Mobility Project, Reason Foundation, 2005-07.
 Committee on the Status of Women in the Economics Profession, American Economic Assoc., 1995-97.
 Advisory Council, South Coast Air Quality Management District (Calif.), 1989-92.

Academic Reviews:

External Review Committee, Transportation Center, Northwestern University, 1999.
 External Review Committee, Dept. of Economics, Oregon State University, 1994.

Study Committees:

Committee on Equity Implications of Alternative Transportation Finance Mechanisms, National Research Council, 2008-2011.
 Committee for the Evaluation of the Congestion Mitigation and Air Quality Improvement Program, National Research Council, 1999-2002.
 Review Committee, Highway Cost Allocation Study, Transportation Research Board, 1995-97.
 Committee for the Study on Urban Transportation Congestion Pricing, Nat'l Research Council, 1992-94.

Referee of journal articles:

American Economic Journal: Economic Policy; *American Economic Review*; *Annals of Regional Science*; *ASCE Journal of Transportation Engineering*; *Berkeley Electronic Press Journals in Economic Analysis & Policy*; *Canadian Journal of Economics*; *Communications in Statistics*; *Contemporary Economic Policy*; *Econometric Theory*; *Econometrica*; *Economic Geography*; *Economic Inquiry*; *Economic Journal*; *Economics of Transportation: Journal of the ITEA*; *Energy Economics*; *Energy Journal*; *European Econ. Review*; *Geographical Analysis*; *Growth and Change International Econ. Review*; *International Regional Science Review*; *Jour. of Public Transportation*; *Jour. of Applied*

Econometrics; Jour. of Business and Economic Statistics; Jour. of Econometrics; Jour. of Economic Geography; Jour. of Economic Literature; Jour. of Environmental Econ. and Management; Jour. of Housing Econ.; Jour. of Law and Economics; Jour. of Policy Analysis and Management; Jour. of Political Economy; Jour. of Public Economics; Jour. of Real Estate Economics and Finance; Jour. of Regional Science; Jour. of the American Real Estate and Urban Econ. Assoc.; Jour. of the American Statistical Association; Jour. of Transport Economics and Policy; Jour. of Transport Geography; Jour. of Urban Economics; Logistics and Transportation Review; National Tax Journal; Policy Studies Journal; Public Finance and Management; Quarterly Journal of Economics; Regional Science and Urban Econ.; Research in Transportation Econ.; Review of Economics and Statistics; Review of Urban and Regional Development Studies; Scandinavian Journal of Economics; Transport Policy and Decision Making; Transport Policy; Transport Reviews; Transportation; Transportation Research A, B, C; Transportation Research Record; Transportation Science; Urban Studies; World Bank Economic Review

Referee of articles for edited volumes (since 1995): *Measuring the Full Costs and Benefits of Transportation; Handbooks in Transport; The Leading Edge of Travel Behaviour Research.*

Referee of book proposals or manuscripts (since 1990): Brookings Institution; Kluwer Academic Publishers; Blackwell Publishers; Harper Collins College Publishers; John Wiley & Sons; American Enterprise Institute; Elsevier; Routledge.

Reviewer of reports (since 1995): National Academy of Sciences/National Research Council; U.S. Congress Office of Technology Assessment; World Bank; U.S. Federal Highway Administration; Reason Foundation; RAND Corporation.

Reviewer of conference papers: International Transport Economics Conference (2) (Apr 09);

Reviewer of dissertation awards: Eric Pas Dissertation Award, International Association for Travel Behaviour Research (Oct 2013).

Program committee for conferences:

Second World Congress of Environmental and Resource Economists (Monterey, Calif., June 2002)
World Conference on Transport Research (Berkeley, Calif., June 2007)
Kuhmo-Nectar Fourth Annual Conference on Transport and Urban Economics (Copenhagen, July 2009)
Summer conference, Association of Environmental and Resource Economists (Seattle, June 2011).

Referee of research proposals (since 1993):

National Science Foundation
California Policy Research Center, Univ. of California
University Transportation Centers: Region One (M.I.T.); Region Two (New York University); METRANS (Univ. of Southern Calif.); University of California Transportation Center
Research Grants Council of Hong Kong
Fund for Scientific Research (Belgium).
Hampton Fund Committee, Univ. of British Columbia
Social Science and Humanities Research Council (Canada)
Univ. of California Energy Institute

Reviewer of fellowship applications (since 1995): Fulbright Fellowship; Guggenheim Foundation; University of Alberta.

Consultant (since 1995): National Cooperative Highway Research Program; San Diego Assoc. of Governments; UK Dept. of Environment, Transport, & Resources; Commission of the European Communities; EcoNorthwest; California Air Resources Board; California Attorney General; Vermont Attorney General; Parsons Brinckerhoff; Energy and Environmental Analysis, Inc.; Resources for the Future; National Transportation Commission (Australia); Weiss and Lurie; Economic Development Research Group; California High Speed Rail Authority; ICF International; Paul, Weiss, Rifkind, Wharton & Garrison LLP.

INVITED TALKS – INTERNATIONAL – SELECTED

Lecture series (3 lectures), University of Tokyo, Graduate School of Public Policy, March 2013.

Presented resource paper, “Long run trends in transport demand, fuel price elasticities and implications of the oil outlook for transport policy” (with Kurt Van Dender), Research Round Table on *Oil Dependence: Is Transport Running Out of Affordable Fuel?*, Joint OECD/ITF Transport Research Centre, Organisation of Economic Co-operation and Development and International Transport Forum, Paris, Nov 2007.

Keynote speaker, “Transport Economics: Impacts on Research and Policy,” European Transport Conference, Noordweikerhout, Netherlands, Oct 2007.

Keynote speaker, “Transport Economics: Impacts on Research and Policy,” Kuhmo Nectar Conference, Urbino, Italy, July 2007.

“Travelers’ Evaluation of Reliability of Service,” Public Transport Forum, Institute of Transport Economics, Oslo, Norway, March 2007. (Repeated at Molde University College, Molde, Norway.)

Panelist, Roundtable on Privatisation and Regulation of Urban Transit Systems, European Conference of Ministers of Transport, Paris, Nov. 2006.

Keynote speaker, “Transport Economics: Impacts on Research and Policy,” Workshop on Transportation and Sustainable Cities, University of Chile, August 7-11, 2006.

Luncheon speaker, “The Future of Congestion Pricing,” First International Conference on Funding Transportation Infrastructure, Banff, Alberta, August 2-3, 2006.

Speaker & discussant, International Symposium on Spatial Economics & Transportation, Sendai, Japan, June 2005.

Luncheon speaker, “Out on a Limb: Pricing Futures,” International Symposium on Road Pricing, Key Biscayne, Florida, Nov. 2003.

Speaker and panelist, NSF Open Workshop on Decision-Based Design, ASME International Design Engineering Technical Conferences, Montreal, Sept. 2002.

Keynote speaker & panelist, "The Transport Sector in an Era of Environmental Management," 60th Anniversary Internat'l Conference of Japan Society of Transportation Economics, Osaka, Japan, July 2001.

Panelist, International Conference on "Urbanization in China: Challenges and Strategies of Growth and Development," Chinese Economists Society, Xiamen, China, June 2001.

Keynote speaker, "Mechanisms of Urban Agglomeration and Its Measurement," Seminar on Urban Economic Policy, Government Institute for Economic Research, Helsinki, Finland, Aug. 1999.

Keynote speaker, "Environment and Transportation Policy: A Review and Prospectus," International Workshop on Environment and Transport in Economic Modelling, University of Venice, Nov. 1995.

"Simulation of Urban Highway Congestion Incorporating Travel Reliability," Int'l Symposium on Transport Econ. & Policy Implications, Korea Transport Inst. & Korean Air Transport Research Inst., Seoul, July '95.

Speaker, workshop on "Internalizing Transport-Related Externalities in the European Union," Directorates-General for Transport and Economic & Financial Affairs, European Commission, Brussels, March 1994.

Speaker, "Real Costs of Transportation and Influence of Pricing Policies," Tenth Convocation of the Council of Academies of Engineering and Technological Sciences, Zurich, Sept. 1993.

INVITED TALKS – U.S. – SELECTED

Speaker, Technical Symposium, Northwestern Univ. Transportation Center 60th Anniversary, Nov. 2014.

Speaker and panelist, "Forecasting for High-Speed Rail in California," special session on Demand Modelling, Kuhmo Nectar Conference on Transportation Economics, Evanston, Illinois, July 10-13, 2013.

Speaker, "Energy Policies for Transportation," Workshop on *Toward a New National Energy Policy: Assessing the Options*, Resources for the Future, Washington, D.C., June 2010.

Speaker, "Gasoline and Carbon Taxes," Conference on *Transportation Revenue Options: Infrastructure, Emissions and Congestion*, Harvard Kennedy School, Cambridge, Mass., May 2010.

Panelist, Workshop on "Pricing and Social Equity," Keston Institute for Public Finance and Infrastructure Policy, Univ. of Southern California, April 2010.

Speaker, Public Affairs Symposium and Forum, Federal Reserve Bank of Atlanta, Oct. 2009.

Speaker and panelist, Forum on "Reinventing Los Angeles: Easing Sprawl, Growth, and Gridlock," Hammer Museum, UCLA, Jan. 2009.

Speaker, "Reducing Congestion through Variable (or Differentiated) Pricing," Workshop on Using Payment Innovations to Improve Transportation Networks, Federal Reserve Bank of Chicago, June 2007.

Speaker, "Urban Transportation Policy: A Guide and Road Map," Conference on "Unraveling the Urban Enigma: City Prospects, City Policies," Wharton School, Univ. of Pennsylvania, May 2007.

Speaker and panelist, Policy Session, Executive Committee, Transportation Research Board, Washington, D.C., Jan. 2006.

Panelist, Roundtable on Transport, Urban Form and Economic Growth, European Conference of Ministers of Transport, Univ. of Calif., Berkeley, Mar. 2006.

Expert Panel on Benefit-Cost Analysis and Public Investment in Transit and Highways, National Research Council & U.S. General Accountability Office, Washington, D.C., June 2004.

Leadoff speaker, Session on Transportation Issues, Conference on Urban Sprawl and Transportation Policy, Weidenbaum Center Forum, Washington University, St. Louis, May 7, 2004.

Lecture series, "Measuring the Demand for Goods" and "Project Evaluation for Decision-making." NSF Symposium on *Decisions and Engineering*, for academic engineers. Univ. of Calif. at Irvine, Oct. 2001.

Public lecture, "Urban Agglomeration and Sprawl: Measurement, Mechanisms, Diagnoses", Resources for the Future, Washington, DC, Mar. 2000.

Panelist and speaker, Chairman's Roundtable: "Urban Sprawl," Lincoln Institute of Land Policy, Cambridge, Mass., Nov. 1999.

Speaker, "Is 'Value Pricing' an Alternative to New Highway Construction for Congestion Relief?" European Science Foundation & National Science Foundation, conference on Social Change and Sustainable Transport, Berkeley, Calif., Mar. 1999.

Speaker, "Congestion Management and Transportation Pricing," (with Martin Wachs), Office of the Secretary, US Department of Transportation, Washington, D.C., March 1995.

Panel speaker and moderator, "Mobility Versus Environment: Transportation's Dilemma," Presidents' Circle Meeting, National Academy of Sciences, Irvine, Calif., Nov. 1993.

PRESENTATIONS AT COLLOQUIA & PROFESSIONAL MEETINGS (since 1997)**Colloquia presentations:**

National Chengchi Univ. (Taiwan, 1997), Academia Sinica (Taiwan, 1997), Univ. of Hong Kong (1997), Hong Kong Univ. of Science and Technology (1997), Washington Univ. (1999), Georgetown Univ. (1999), Harvard Univ. (1999), M.I.T. (1999), Boston College (1999), U.S. Environmental Protection Agency (2000), Tinbergen Institute (Amsterdam, 2000), Imperial College (London, 2000), Univ. of Calif. at Davis (2000), World Bank (2000), Doshisha Univ. (Kyoto, Japan, 2001), Univ. of Maryland at College Park (2000, 2004), Univ. of Illinois at Urbana-Champaign (2004), Univ. of Texas at Austin (2004), Federal Reserve Bank of Chicago (2004), Univ. of Southern California (2004), Univ. of Tokyo (2005), Brigham Young Univ. (2005), Resources for the Future (2000, 2006), Oregon State Univ. (2006), Portland State Univ. (1992, 2006), Stanford Univ. (2004, 2006), Federal Reserve Bank of New York (2007), University of Leeds (2007), Danish Transport Research Institute and University of Copenhagen (2007), Universitat Autònoma de Barcelona (2008), Universitat de Barcelona (2008), Catholic University of Leuven, Belgium (2000, 2008), Northwestern Univ. (2003, 2004, 2009, 2010), Yale Univ. (2013), Cornell Univ. (2013).

Presentations of papers at conferences and meetings of professional societies:

American Economic Association (1998, 2002); American Real Estate and Urban Economics Association (1997); Regional Science Association (1999, 2006); Transportation Research Board (2000); International Assoc. of Travel Behaviour Research (1997, 2003); Conference on Environmental Economics, UC Santa Barbara (2001); Second World Congress of Environmental and Resource Economists (2002); STELLA (Sustainable Transport in Europe and Links and Liaisons with America) (2003); Conference on Theory and Practice of Congestion Charging, Imperial College, London (2003); Brookings-Wharton Conference on Urban Affairs (2005); World Conference on Transport Research (2007); Oslo Workshop on Valuation Methods in Transport Planning (2007); Kuhmo-Nectar Conference on Transport and Urban Economics (Amsterdam 2008, Copenhagen 2009, Valencia 2010, Stockholm 2011, Berlin 2012, Chicago 2013, Toulouse 2014); Sivitanidou Research Symposium, Lusk Center for Real Estate, Univ. of Southern Calif. (2009); Internat'l Transport Econ. Conference, Minneapolis (2009).

Invited discussant at conferences and meetings of professional societies:

American Economic Assoc. (1997); Regional Science Assoc. (1999); Transportation Research Board (1997); Brookings-Wharton Conference on Urban Affairs (2000); Workshop on Industrial Organization and Public & Environmental Economics, Stanford Univ. (2003); Sivitanidou Research Symposium, Lusk Center for Real Estate, Univ. of Southern Calif. (2006); Resources for the Future (March 2007); National Bureau of Economic Research (2000, 2002, 2008); Lincoln Institute of Land Policy (2010).

Chair or organizer of sessions:

American Economic Assoc. (1997); Second World Congress of Environmental & Resource Economists (2002); Conference on "Transportation Financing in California," Center for Urban Infrastructure, UC Irvine (March 2003); Conference on "Taxation and Decentralization," Center for the Study of Democracy, UC Irvine (2005); World Conference on Transport Research (2007).

GRANTS

- 2011-14 "Fuel Efficiency Regulations of Light-Duty Vehicles," U.S. Dept. of Transportation," via Resources for the Future & Brookings Institution (\$55,000) (w/ C. Winston).
- 2010 "Response of Light-Duty Vehicle Travel and Fuel Consumption to Fuel Costs," UC Center for Energy and Environmental Economics (\$13,686).
- 2006-07 "Effects of Policies to Reduce Light-Duty Vehicle Fuel Consumption," Energy & Environmental Analysis, Inc., subcontract from US Dept. of Energy (\$110,000) (w/ K. Van Dender).
- 2005-06 "The Impact of Transportation Fuel Conservation Strategies in California," University of California Energy Institute (\$35,000).

GRANTS – (Continued)

- 2001-02 "Fuel Taxes and the Control of Externalities from Motor Vehicles," University of California Energy Institute (\$39,400).
- 2000-01 "Diversity in the Value of Travel Time and Reliability," U.S. Dept. of Transportation and Calif. Dept. of Transportation (\$15,687). Funded through U.C. Transportation Center.
- 2000-01 "Viability of Public Transit with Road Pricing Measures," University of California Energy Institute (\$24,900).
- 1999-2001 "Travel Demand Modeling for State Route 91 Express Lanes," U.S. Dept. of Transportation (\$30,000). Funded as subcontract to Cal Poly San Luis Obispo.
- 1999-2000 "Viability of Value Pricing Demonstrations," U.S. Dept. of Transportation and Calif. Dept. of Transportation (\$70,000). Funded through U.C. Transportation Center.
- 1997-98 "Travel Behavior on a Congestion Pricing Project," U.S. Dept. of Transportation and Calif. Dept. of Transportation (\$58,912). Funded through U.C. Transportation Center.
- 1996-99 "Benefits, Acceptance and Marketability of Value-Pricing Services," ITF Intertraffic, a subsidiary of Daimler-Benz AG (\$149,500).
- 1995-96 "Valuation of Travel-Time Savings and Predictability in Congested Conditions for Highway User-Cost Estimation," National Cooperative Highway Research Program, National Research Council (\$70,126) (with David Lewis, Hickling Corp.).
- 1993-94 "Congestion Pricing and Financial Self-Sufficiency," U.S. Dept. of Transportation and Calif. Dept. of Transportation (\$22,379). Funded through U.C. Transp. Center.
- 1993-94 "Socio-Economic Attributes and Impacts of Travel Reliability: A Stated Preference Approach," California Department of Transportation (\$120,036). Funded through California PATH (Partners for Advanced Transit and Highways).
- 1988-93 "Travel Flows and Sub-Center Development," U.S. Dept. of Transportation and Calif. Department of Transportation (\$222,708) (with G. Giuliano). Funded through U.C. Transportation Center, five separate proposals and grants (first joint with R. Teal).
- 1987-88 "Methanol Fuel for Los Angeles Area Transit Buses: Costs and Benefits": The John Randolph Haynes and Dora Haynes Foundation (\$34,532).
- 1985-87 "Aggregate Welfare Measures and Probabilistic Criteria for Welfare Improvement": National Science Foundation (\$23,863).
- 1985-86 "Costs and Benefits of Methanol as a Replacement for Oil Fuels": Univ. of California Energy Research Group (\$5,000), (with D. Brownstone, S. Erfle, G.J. Fielding, and C. Lave).
- 1984-89 "Effects of Marginal Cost Pricing of Motor Freight", "Work Trip Scheduling and Traffic Congestion", "Activity and Transportation Systems Development", "Costs and Benefits of Methanol Fuel", "New Specification Tests for Travel Demand Models", "Statistical Analysis of Road-Test Data": Univ. of California, Institute of Transportation Studies (\$79,821).
- 1982-84 "Discrete Choice Econometrics: Estimation of Two Probability Models": National Science Foundation (\$33,402).
- 1980-82 "Qualitative Choice Analysis and Trip Timing Behavior": National Science Foundation (\$50,982), (with D. Brownstone).
- 1977-78 "Analysis of Urban Travel Demand": National Science Foundation (\$24,400).

PUBLICATIONS

Books

Bradbury, Katharine, Anthony Downs, and Kenneth A. Small. *Futures for A Declining City: Simulations for the Cleveland Area*, Academic Press, 1981.

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TEACHING EXPERIENCE

(*indicates newly initiated courses)

Undergraduate courses:

- Introduction to Economics (for non-majors)
- Principles of Microeconomics (for majors)
- Urban Economics*
- Transportation Economics*
- Environmental Economics*
- Industrial Organization
- Intermediate Microeconomic Theory
- Economics of Alcohol Fuels*
- Freshman Seminar on Global Warming*
- Independent Study (various)

Graduate courses:

- Transportation Economics*
- Urban Economics*
- Discrete Choice Econometrics*
- Environmental Economics Writing*
- Graduate Colloquium in Economics
- Colloquium in Transportation Science
- Independent Study (various)
- Woodrow Wilson School of Public and International Affairs, Princeton Univ.:
 - Workshop on Declining Cities*;
 - Urban Economics (for Public Policy students)
- Harvard University:
 - Urban and Regional Economics;
 - Seminar in Urban Economics, Transportation, and Regional Economic Development

Other Teaching Activities:

Director of Undergraduate Studies, Dept. of Economics, Princeton Univ. (1979-82)
 Associate Dean for Graduate Education, School of Social Sciences, U.C. Irvine (1986-92)
 Director of Graduate Studies, Dept. of Economics, U.C. Irvine (1984-86)
 Director of Undergraduate Studies, Dept. of Economics, U.C. Irvine (2001- 2003)
 Graduate dissertation committees
 Freshman advising (1996, 1999, 2002, 2003)
 Undergraduate and Graduate qualifying examinations
 External examiner of PhD. Thesis for: Univ. of Adelaide (Australia); State Univ. of N.Y. at Buffalo ('99)
 Supervise: Junior independent papers, Senior theses, Graduate independent papers
 Participant, coordinator: faculty/graduate study group in transportation economics (1987-present).
 Reading lists and course outlines, in Edward Tower, ed., *Economics Reading Lists, Course Outlines, Exams, Puzzles and Problems* (Eno River Press), 1981, '85, '90, '95: Urban Econ. (undergrad & graduate), Transportation Econ. (undergrad & grad), Discrete-choice Econometrics (graduate).
 Selection committee, Justin Zubrod Paper Competition, Northwestern Univ. (June 2004)
 Screening committee, Grad Student Paper Competition, N. American Regional Science Council (2010)
 Guest lecturer:
 Advanced Travel Demand (graduate), M.I.T. (Nov. 1991)
 Transportation Planning (graduate), UCLA (Feb. 1994)
 Introduction to Social Sciences (lower division), UCI (Jan., May 1994)
 Lecture series - Transportation and Environment, Catholic Univ. of Leuven, Belgium (May 2000)
 Lecture series - Transportation and Land Use, Royal Inst. of Technology, Stockholm (May 2000)
 Travel Demand (graduate), Northwestern Univ. (May 2004)
 Faculty, ITEA Summer School on Transportation and Urban Economics (formerly Kuhmo Nectar):
 Urbino, Italy: July, 2007
 Amsterdam: June-July 2008
 Copenhagen: June-July 2009
 Valencia, Spain: July 2010
 Stockholm: June 2011
 Berlin: June 2012
 Chicago: July 2013
 Toulouse, France: June 2014
 Transportation Economics (graduate), one-week short course, part of LOG904, Seminar in Logistics, Molde University College, Molde, Norway [Nov. 2007; Oct. 2008; Oct. 2009; Aug. 2010; Sept. 2011]
 Transportation Economics (graduate), one-week short course, Valencia Summer School on Business and Economics, Valencia, Spain, July 2009.
 Faculty, Cost-Benefit Analysis (graduate), special one-week course at Molde University College, Molde, Norway, Aug. 2010.
 Faculty, Summer School in Environmental and Energy Economics, University of California Center for Energy and Environmental Economics, Berkeley, Calif., Aug. 2011.

UNIVERSITY SERVICE, UNIVERSITY OF CALIFORNIA

Economics Department: Department Chair (1992-95); Vice Chair (2001-03); Co-chair of Recruiting Committee (1983-84, 1998-99, 2000-01); Member of Recruiting Committee (2004-05); Director of Undergraduate Studies (2001-03); Director of Graduate Studies (1984-86); Graduate Committee (1983-86, 1998); Undergraduate Honors Committee (1985-87); Visitors Committee (1983-84); Personnel committees for faculty promotions, various (1983-present).

School of Social Sciences: Associate Dean for Graduate Education, 1986-92; Acting Dean, various times, 1986-92; Distinguished Student Scholar Prize Committee, 1986; Executive Committee, Institute for Mathematical Behavioral Sciences, 1994-97; Ad Hoc Committee for Graduate Student Award, 1998; Acting Department Chair for personnel actions of current department chair, 2005-07.

Irvine Campus: *Ad hoc* personnel committees for faculty promotions, various, 1984-present; speaker at campus-sponsored conferences, 1983-present; Executive Committee, Inst. of Transportation Studies, Irvine branch, 1984-1991; faculty representative to Social Science Librarian Search Committee, fall 1985; Committee on Educational Policy, 1985-87 (Chair, Policy Subcommittee, 1986-87); Research Computer Advisory Committee, 1986-88; external review panel for UCI writing programs, winter-spring 1989; search committee for assistant professor in Civil and Environmental Engineering, 1996; review committee for UCI Pacific Rim research proposals, 1997; nominating committee, Phi Beta Kappa, 1997; Committee on Academic Freedom, 1996-98 (Chair, 1997-98); Council on Rights, Responsibilities and Welfare, 1998-99 (Vice Chair); Campus Review Panel, School of Engineering Graduate Program Review, 1998-99; Chair, Faculty Search Committee, Inst. of Transp. Studies & Program in Transp. Science, 2003-04. Member, UCI Expert Database (referrals to media), continuing.

University of California system-wide: Subcommittee on Housing, Faculty Welfare Committee, Academic Senate, U.C. System-wide, 1983-86 and 1991-93; Executive Committee, Institute of Transportation Studies, U.C. System-wide, 1984-86; Executive Committee, U.C. Transportation Center, 1996-99.



Kenneth Wm. Vieth III
President and Senior Analyst
ACT Research Co., LLC
11545 North Marr Rd.
Columbus, IN 47203

BIO:

After graduating from Southern Illinois University, Vieth spent six years in city government and education before joining ACT Research in 1991. Vieth became a partner at ACT in 2000 and the company's President in 2009. Vieth oversees commercial vehicle analysis and forecasting at ACT and is the company's principal heavy truck and trailer market analyst.

In that capacity, Vieth has become an advisor to the commercial vehicle OEMs and suppliers, the investment community, trucking companies, and other businesses affiliated with the industry. In 2012, Vieth was named as the consulting economist to the National Private Truck Council (NPTC) and in 2013 was the top forecaster in the Chicago Federal Reserve Bank's consensus forecast. Also in 2013, ACT was invited to become one of the 50 firms participating in the Blue Chip Economic Indicators.

In 2008, Vieth cemented a partnership with China's State Information Center to provide forecasts to Western companies interested in understanding commercial vehicle demand trends in China.

Since its inception in 1986, ACT Research has become the leading source of North American commercial vehicle market data, forecasting, and analysis.

APPENDIX B

CHARGE TO REVIEWERS

PEER REVIEW CHARGE

DTNH22-13-D-00298 – Task Order 0003, Report 2

February 2015

External Peer Review of Draft Report: “Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022.”

BACKGROUND

In September 2012, NHTSA competitively awarded a contract to Southwest Research Institute (SwRI) to conduct research in support of the next phase of Federal fuel efficiency (FE) and greenhouse gas (GHG) standards. The scope encompassed technologies for chassis and final-stage manufacturer vehicles and trailers, maintenance cost, material application, future design, electric and hybrid propulsion systems, capital investment, retail cost/payback and any other applicable advanced technologies. Estimates of the costs, fuel savings effectiveness, availability, and applicability of technologies were done for each individual vehicle class category.

The resulting report series consists of three sequential report documents, which are being peer reviewed separately. The reports in the series are all from the same project, and involve the same technologies, engines, and vehicles, but due to size have been separated into three documents to facilitate review and publication. This charge pertains to the second report, *Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Cost Study*, which documents the analysis of estimated costs for potential fuel efficiency/GHG improving technologies. Tetra Tech, a subcontractor to SwRI, performed the cost analysis with the guidance and direction of SwRI and NHTSA.

REPORT OVERVIEW

The cost analysis for the fuel efficiency technologies is presented in three main parts: 1) Incremental Cost Analysis, 2) Life Cycle Cost Analysis and 3) Indirect Benefits. Tetra Tech assessed the projected costs based on literature review, pricing guidelines, and past efforts (Tetra Tech had performed similar work in the past as the corporate entity TIAX) for determining technology costs.

- 1) **Incremental Cost Analysis.** The incremental retail prices are evaluated relative to the prices of the specific baseline technologies that would otherwise be used in the vehicles if the fuel efficiency and emissions reduction technologies were not implemented. These prices include the technology components as well as their installation and incorporation in the vehicle. Incremental retail prices account for all costs associated with the manufacturers and suppliers’ production and sale of the technologies to the retail purchaser.

The ranges of incremental price values found in the literature are scaled to project incremental prices using manufacturing volume-dependent cost curves. The cost curves consist of two components:

- Direct costs, which encompass materials, labor, and other relatively fixed costs of technology manufacture.

- Indirect costs, which are divided into production overhead (warranty, R&D/engineering, and depreciation and amortization), corporate overhead, selling and dealer support (distribution, marketing, dealer support, and dealer discount), and net income to the manufacturer. The decrease in indirect costs over time is used to estimate the decrease in costs as the cumulative manufacturing volume increases over time (different indirect cost factors for different technology complexities).

This report draws upon reported incremental retail prices of published studies and data (especially sources that had been peer reviewed). A teardown analysis was not performed in this report to determine the breakout between the direct and indirect cost elements.

- 2) **Life Cycle Cost Analysis.** The life cycle cost portion of the assessment examines the costs of using the technologies during the vehicles' lifetimes. In addition to the initial purchase costs of the technologies, the technologies' effects on fuel consumption, brake maintenance, major overhaul intervals, vehicle life, and other operations and maintenance (O&M) costs are quantified. Note that, at NHTSA's direction, full life cycle analysis was not performed. Instead, life cycle cost elements are reported (depending upon available data), with the goal to enable NHTSA to perform its own full life cycle analysis using its own assumptions regarding fuel costs, discount rates, and other financial variables.
- 3) **Indirect Benefits.** Indirect economics effects encompass the broader impacts not captured through incremental and life cycle costs. These effects occur at the community- and economy-wide level and include: fleet turnover; rebound; environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs. Where quantification data was not available, Tetra Tech qualitatively described the effects.

The study to be reviewed, *Report #2 - Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Cost Study*, includes two documents: the main report and accompanying appendices. The folder labeled **Review Documents and Appendices** contains the main report ("Report 2_Tetra Tech Cost Report 140829_Peer Review_Final.pdf") and the appendices ("Report 2_Tetra Tech Cost Report Appendices 140829_Peer Review.pdf") documents. In developing your responses to the charge questions below, please read the entire study, including the appendices, which provide additional details about the baseline technologies, prior technologies assumed, supporting data, and cost references.

To provide a comprehensive technical background on fuel efficiency technologies studied, a draft copy of Report #1 including its Appendices A through D are also provided for your reference. The folder labeled **Background Reference Material** contains the main report ("Report 1_SwRI MDHD Tech Report 1-17869-Peer Review_v2.pdf") and the appendices ("Report 1_SwRI MDHD Tech Report 1 Appendices -17869-Peer Review.pdf") documents. SwRI's descriptions of the Gasoline Engine Technologies, Diesel Engine Technologies, Vehicle Technologies, and Bottoming Cycle Technology can be found in Appendices A through D, respectively. These Report #1 documents are provided as reference materials only and do not need to be reviewed.

CHARGE QUESTIONS

In your written comments, please respond to all of the following questions that are within your area of expertise and identify additional topics or depart from these examples as necessary to best apply your particular area(s) of expertise. Your comments shall be sufficiently clear and detailed to allow readers to thoroughly understand their relevance to this study. **Additional supporting data files, engine maps/models, images, and materials may also be provided to reviewers upon request.**

Note that the first three sets of questions focus on Sections 3, 4, and 5 of the main report, respectively. The questions in “General Comments” and “Overall Recommendation” pertain to the main report as a whole.

1. Incremental Cost Analysis (Section 3)

- 1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.
- 1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.
- 1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?
- 1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

2. Life Cycle Costs (Section 4)

- 2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories? If not, what can be improved and how?
- 2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

3. Indirect Effects (Section 5)

- 3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?
- 3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

4. General Comments

- 4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.
- 4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?
- 4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?
- 4.4 Please provide any other comments you may have on this report.

5. Overall Recommendation

- 5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable? Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

APPENDIX C

INDIVIDUAL REVIEWER COMMENTS

COMMENTS SUBMITTED BY

Bruce M. Belzowski, M.A.
Managing Director, Automotive Futures
Transportation Research Institute
University of Michigan
Ann Arbor, Michigan

Bruce M. Belzowski

3/5/15

Review of “Commercial Medium- and Heavy-Duty (MD/HD) Truck Fuel Efficiency Technology Cost Study”

Introduction

Overall, I admire this attempt to investigate the total costs involved in developing, manufacturing, and selling these new technologies. It is a difficult task because of the uncertainty surrounding the development of many of these technologies for the truck market.

Estimating the prices/costs connected with direct costs, production overhead, corporate overhead, selling and dealer support, and net income is ambitious, and I commend the authors on tackling such a complex topic. The ways the authors use to try to account for all of these elements of the total costs analysis are very interesting. I wish I could comment on how to improve them, but this is outside my expertise.

One area of concern has to do with the audience for this report. The report tries to simplify the complex analyses that were devised to generate estimates for each technology, but I think the resulting document still is difficult to understand. This is always a challenge for a technical report. How does one make the complex results understandable to the people who want to use the results for developing policy? One way is to summarize the results in an executive summary, especially since many people will not read the full text either because of time or because of its complexity.

1. Incremental Cost Analysis (Section 3)

1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.

- I do not know of any other potential sources for this data, but because many technologies are in the development stage, constant updating of their progress is needed in order for policy makers to make good decisions. We will see this during the mid-term assessment for light duty vehicle CAFE. The regulators meet with the manufacturers and suppliers frequently to discuss where they are in developing and marketing the technologies the industry said they would pursue over the next 10-15 years. And the regulators find that some new technologies that they didn't expect to play a role are now in development. All this communication provides regulators important input that goes along with reports such as this one. It would be nice if the authors could easily update their models dynamically as new information becomes available or else the report will become dated.

1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis?

- Very few people will understand why the authors used a squared term in their regression equations. But for reviewers such as myself, I need to know how estimates were generated. I need to know the

details. For this report the authors are very thorough about describing what other reports have found about these technologies. One of my issues with the Incremental Cost Analysis is the lack of explanation, either in the body of the report or in the appendices, of how the estimates for each of the variables (production overhead etc.) were created. The authors show the reader the main outline of the analysis, but they do not show the details. I know the details are complex, but I would like to see them, either in the body or in an appendix.

- My other issue focuses on the lack of discussion of the results for each technology. Is the model for a particular technology a good estimate of all the costs/prices or is it a weak model? I have concerns about the strength of the models for some of the technologies. Because of the lack of a teardown analysis that examines all the parts of a technology, the reliance on others' estimates sometimes creates a wide range of possible prices. When I look at the appendices to see what the estimates from other sources are, I see a wide range of estimates for some of the technologies. It looks like the authors are showing this in the vertical bars in the graphs in the body of the report (though this is not noted anywhere that this is the case).
- Nearly all the technologies have wide ranges, whether the technologies are very expensive or even if the technologies are not considered very expensive. Even if a technology is considered less expensive, a wide range of these values will affect the average price as well as the estimates for the components (production overhead, company overhead, etc.) Below, I have broken the technologies with relatively wide ranges into three groups: more expensive technologies with wider ranges, moderately expensive technologies with wider ranges, and less expensive technologies with wide ranges:
 - More expensive technologies
 - Advanced bottom cycling (\$22,500 range)
 - Hybrid-electric powertrains (\$21,000)
 - Diesel APU (\$6,000)
 - Battery APU (\$5,000)
 - Class 4 to 6: Dual clutch automatic (\$1,900)
 - Class 8: Dual clutch automatic (\$5,000)
 - Class 2b and 3 Weight reductions (\$2,000)
 - Class 4 to 6 Weight reduction (\$4,000)
 - Class 8 Weight reduction (\$12,000)
 - Moderately expensive technologies
 - Lean Burn GDI with SCR: Class 2b and 3 / Class 4 to 6 (\$1450)
 - Turbocharging and downsizing: (\$700)
 - Engine downsizing: (\$2,000)

- Stop/Start diesel: (\$1,000)
- Air handling improvements: (\$725)
- Mechanical turbo compound: (\$1,000)
- Electric turbo compound: (\$1,500)
- Fuel-fired heater (\$600)
- Shore power (\$1,800)
- Boat tail (\$800)
- Full trailer skirt (\$325)
- Full tractor skirt (\$500)
- Class 4 to 6 improved transmissions: gas (\$500)
- Class 4 to 6 improved transmission: diesel (\$600)
- Class 8 improved transmissions: (\$1,700)
- Class 4 to 6 automated manual transmissions: (\$700)
- Class 8 automated transmissions: (\$2,000)
- Automated tire inflation (\$800)
- 6 X 2 axles (\$1,600)
- Less expensive technologies
 - Class 2b and 3 (\$300 range) / class 8 variable displacement pump (D) (\$300 range)
 - Variable valve actuation: Class 8 High 1 and 2 (\$450)
 - Cylinder deactivation: Class 2b and 3 / Class 4 to 6 (\$525)
 - Low friction engine oil: Class 8 (\$95)
 - Engine friction reduction: (\$225)
 - Reduced aftertreatment backpressure: (\$575)
 - Air-conditioner improvements: (\$350)
 - Cab insulation (\$250)
 - Air compressor (\$300)
 - Aero gap filler (\$350)
 - Class 2b and 3 improved aerodynamics (\$425)
 - Class 2b and 3 Improved gas transmissions (\$400)
 - Class 2b and 5 / Class 4 to 6 low rolling resistance tires (\$38)
 - Single wide tires (\$100)
 - Low friction axles and lubricants (\$300)

- Fitting a line through the four points on the graph is very likely the best/most conservative estimate for a set of data, but the practical use one can take away from the wide range of values, I argue, is not as useful as it is for the analyses where the range of costs/prices is narrower. The wide range of values also plays a role in the accuracy of the estimates for components of the Incremental Cost Analysis. Generating estimates for the components (production overhead, etc.) based on this wide range of values needs to be addressed by the authors in order to help the reader make better use of the results.
- P.14 onwards: “Example using the methodology and application of Indirect Cost Factors (ICF)”. I find these “Examples” very confusing. Are they there to show me how all the different combinations of adjusting variables described earlier are used to create the estimates that are used throughout the following tables of technologies? If so, they sow more confusion than clarity. I think it would be much better to walk through one of the technologies, showing all the calculations used to come up with each of the estimates on the graph and in the table. This gives the reader a better understanding of how the authors used all the different adjustments they discuss earlier in the report.
- I can see the regression analysis the authors are using is very complex, but not being able to describe what they are doing makes the whole process less understandable. I’ve used complex equations like this in other reports, and I found that though much of it is lost on the people reading the report, at least showing them the variables that make up one of the equations would be helpful, if not in the main text then in an appendix.

Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

- I think it is a matter of clearly showing what they are doing as well as describing what the results mean. This is missing from this report overall.

1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?

- P. 27: “In cases where single technologies are combined into a technology package, the price of the package is defined as the sum of the prices of the components.” While this seems reasonable, one would think that a package/system of technologies should reduce costs.
- P.13: Compared to the North American light duty market, the market for Class 2b through Class 8 trucks is small. This is a key issue for any company considering investing in developing these technologies. This means that various suppliers and manufacturers that are developing and selling new technologies are fighting over small shares of the market and potentially low volumes. Of course, a company that comes up with a great new technology will have the lead for a few years, but industry leadership in one technology does not last long in the auto industry because competitors quickly adjust and develop their own versions of a technology, if they think they can do it profitably. Also, the volume assumptions for technologies do not seem to account for potential global volumes as well as North American-only volumes. Auto manufacturers and suppliers are global, and they make business decisions based on potential volume wherever it is.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

- P. 14 “It is important to note that because prices are for cumulative volumes, volumes across vehicle classes may be additive. For example, if the same gasoline engine is used in both Class 2b&3 and Vocational vehicles, the industry total volume for a technology on that engine will include volumes from both vehicle categories. As a result, the incremental price of the technology may be lower than the price according the volume in a single vehicle category.” I think this should be noted where possible in the graphs, so the reader knows when the authors are crossing boundaries and when they are not.

2. Life Cycle Costs (Section 4)

2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. If not, what can be improved and how?

- Two major issues are of concern for this section: Missing data and timeliness. There is a lot of missing data in this section. This makes it of less value to the policy makers, except for technologies where data is available. But then there is the issue of timeliness. It is 2015. Showing me production volume for 2012 is useless at this point in time. It makes me wonder how old the data is in the section overall. Some of the lifecycle costs have probably not progressed much since 2012, while others probably have. This is always an issue with research that is focused on developing technologies. By the time the report is out, some of the lifecycle costs have already changed, while others are still where they were in 2012. I think there needs to be a discussion of this issue in the report in order to help the reader who may want to use the information for policy decisions. It sounds like I’m asking the authors to update this section or maybe drop it altogether if the estimates are dated at this point.
- For the Lifecycle Analysis, I was expecting the results of this analysis to be rolled into the Incremental Cost Analysis (or vice versa), but too much missing data in this section looks like it precludes this happening. The authors note that others have addressed this issue more thoroughly begs the question of whether this section should even be in the report or maybe the results of the other reports should be incorporated into this section.

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

- I can’t address this point other than to say that there to be too much missing data for too many technologies.

3 Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

- This analysis seems to have covered the relevant indirect effects, but like the lifecycle section, I was expecting the impact of these effects to be incorporated into the Incremental costs models (or vice versa).

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

- For Fleet Turnover Effects, the 2007 rule was designed so that fleets had to be in compliance by 2010. The graph for this section should show more updated info on sales to see the effect of the rule during and after its implementation in order to see the total effects of the rule on sales.
- For Human Health Effects, Table 52 is confusing. What does an 11 mean? \$11 dollars annually?
- For Incremental Weight Effects: “Additional weight of new vehicle technologies could partially offset the fuel efficiency gains from the new technology.” Doesn’t the improved fuel economy that the new technologies boast of include the weight of the technology itself? Doesn’t the fuel economy of the hybrid system of the Prius assume a certain increase in weight?

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

- I have a mixed view about this report. On the one hand it tries and succeeds for the most part in modeling a very complex relationship among very diverse components of new vehicle technology (production overhead et al). Yet, I see some major issues related to the need for a conclusion and executive summary that discusses the results of the analyses, as well as the need for a clearer description of how the models were assembled and how the graphs are to be interpreted.
- Table 1 is full of abbreviations that are not noted on the abbreviations section. These abbreviations need to be added to the abbreviations section.

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

- P.1 “Incremental retail prices are evaluated relative to the prices of the specific baseline technologies that would otherwise be used in the vehicles if the fuel efficiency and emissions reduction technologies were not implemented.” Does this mean they are subtracting the cost of the

current (specific baseline technologies) from the cost of new technologies with the resulting cost for that component being part of the “incremental retail price?”

- The intro to the report needs to spend more time describing the market in order for the reader to understand the impact of these technologies on manufacturers and suppliers. How big is this market in the US? How big is it globally? Is the report focusing on the US or the global market? This is very important because it will affect the investment global manufacturer and supplier companies will put into developing new technologies. Also, a large number of manufacturers and suppliers fighting over relatively small volumes is a disincentive to invest in this market. So understanding the potential volume in this market is important.
- Are these technologies that are estimated based on the number of new trucks sold per year or are there aftermarket implications? If a technology can be installed in the aftermarket, then potential volumes increase dramatically. If they cannot, then volumes are much lower.

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

- The strongest parts are the attempts to model complex cost/price processes in the Incremental Cost Analysis, and the thoroughness of the secondary research that appears in the Appendices.
- The weakest parts are the lack of analysis of the results of the study at the beginning and end of the report, the lack of a detailed explanation of how the graphs in the Incremental Cost Analysis were created and an evaluation of the value or strength of each of the models, the missing data and timeliness of the data in the Lifecycle section, the lack of connectivity among the three sections in terms of modeling, and the need for more info about the Class 2b to Class 8 truck market.

Some smaller issues include:

- The graphs starting on P. 21 are hard to read, but the accompanying tables help the reader understand the data in the graphs.
- The vertical lines in the charts need explanation. I assume they are the high and low values for the data gathered from the outside sources, especially for the 50K assumption.
- Also sometimes when the lines cross the total incremental price and the direct costs lines, it is hard to tell which variable the line is representing? (Figures 1-7)

4.4 Please provide any other comments you may have on this report.

None.

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

I think this report is acceptable with revisions. Whether NHTSA, EGR, and the authors consider them major revisions is up to them. I refer to my listing of the weaknesses of the report for justification. From the weaknesses section: The weakest parts are the lack of analysis of the results of the study at the beginning and end of the report, the lack of a detailed explanation of how the graphs in the Incremental Cost Analysis were created and an evaluation of the value or strength of each of the models, the missing data and timeliness of the data in the Lifecycle section, the lack of connectivity among the three sections in terms of modeling, and the need for more info about the Class 2b to Class 8 truck market.

COMMENTS SUBMITTED BY

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Roger H. Bezdek Review of Draft Report: “Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022”

March 5, 2015

1. Introduction

Detailed Comments on Introduction

P. 1, ¶ 1: “This report examines the costs of implementation, nominally in 2011 U.S. dollars.”

This wording is confusing and incorrect. By definition, “nominal dollars” are not inflation-adjusted and refer to the dollars of the year in question. The correct terminology is “constant 2011 dollars” and the report should reflect this.

P. 1, ¶ 2: “Incremental retail prices are evaluated relative to the prices of the specific baseline technologies that would otherwise be used in the vehicles if the fuel efficiency and emissions reduction technologies were not implemented. These prices include the technology components as well as their installation and incorporation in the vehicle. Incremental retail prices account for all costs associated with the manufacturers and suppliers’ production and sale of the technologies to the retail purchaser.”

This statement is questionable. It is very difficult to precisely estimate future retail prices that would occur if the new standards were not implemented.

P. 1, ¶ 4: “Indirect economics effects encompass the broader impacts not captured through incremental and life cycle costs.”

The report’s conception of indirect economics appears to be somewhat flexible in different sections of the report. It should also be distinguished from the conventional economic direct and indirect effects that are derived via interindustry input-output analyses.¹

Point of Clarification

My major point here is that most analysts when they see the phrase “indirect economic impacts” think immediately of those derived using standard economic input-output (I-O) analysis.

I-O analysis has been widely used for the past half-century to estimate the total (direct, indirect, and induced) impacts created by an activity, expenditure, or program

- Direct impacts are those created directly in the specific activity or process
- Indirect impacts are those created throughout the required inter-industry supply chain
- Induced impacts are those created in supporting or peripheral activities; e.g., in a restaurant across the street from a vehicle manufacturing plant

¹ After submitting final comments, NHTSA requested that the reviewer provide a clarification on this statement. The reviewer’s response has been inserted under *Point of Clarification*.

- Total impacts are the sum of all of the impacts created
- For simplicity, analyses sometimes include induced impacts in the indirect category

The total (direct, indirect, and induced) impacts concept is the accepted methodology widely used in studies of this nature and in the peer-reviewed literature.

Tetra-Tech in the study is using a different definition of indirect economic impacts. This is O.K., but Tetra-Tech should be careful to precisely define what they are talking about to distinguish their concept from the standard, accepted definition of indirect effects. Such a discussion will also add credibility to the report, since it will indicate that Tetra-Tech is aware of the standard I-O concepts.

2. Fuel Efficiency and Emissions Reduction Technologies

Detailed Comments on Section 2

P. 2, ¶ 1: “At present, vehicles in this category operate primarily with diesel engines, though improving gasoline engine technologies may encourage the increased use of gasoline engines in the Vocational category.”

While diesel engines can offer substantial fuel efficiency advantages, it should be noted that the cost of meeting new emissions standards with gasoline engines is usually much less than with diesel engines. Diesel engines start with a significant cost disadvantage compared to gasoline engines, because of their greater strength (to withstand the high-cylinder pressures of compression ignition) and their far more sophisticated fuel systems. Diesel fuel systems have injection pressures of 1,600 to 3,000 bar, while even the expensive (by gasoline engine standards) GDI fuel systems require only 100 to 200 bar. Port injection systems for gasoline engines typically use injection pressures of only a few bar. The need to create and control extreme pressures has a major effect on diesel fuel system cost.

When the higher cost of diesel engines is added to the significantly higher cost of diesel emissions control after-treatment, there is a powerful market incentive to move toward gasoline engines, except where the durability of the diesel engine is required. In recent years, diesel engines have lost market penetration to gasoline engines in some classes of MD/HD vehicles. Studies also indicate that recent emissions regulations may be accelerating the trend toward gasoline engines in medium-duty trucks. Will this also be the case with MD/HD vehicles? The draft report should address this important issue.

Charge Questions

1. Incremental Cost Analysis (Section 3)

1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.

The published studies and data cited do not include all key relevant data sources for the target technologies. Numerous additional sources could have been consulted, or at least listed. Examples of some (but not all) of these potential sources are listed below at the end of my formal comments.

In the whole draft report, “peer reviewed studies” is mentioned only once, on p. 133. Virtually all references cited in the draft report are not peer reviewed. This is very disturbing and weakens the report’s credibility.

Further, of the approximately 45 references listed, there is only one that is a published peer reviewed study (Lepeule, J., F. Laden, D. Docker, J. Schwartz, "Chronic Exposure to Fine Particles and Mortality: An Extended Follow-up of the Harvard Six Cities Study from 1974 to 2009," *Environmental Health Perspectives*; 120:965-970, July 2012), and even it does not directly address MD/HD Truck Fuel Efficiency Technology issues.

I have listed at the end of my formal comments some additional sources that could have been consulted. These are meant to be indicative, not comprehensive. It is the job of the draft report authors, not the report reviewers, to conduct a rigorous and comprehensive literature review – including peer reviewed studies published in the literature -- as an integral part of the research.

1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

The methodology used in the report for determining incremental retail prices contends that it relied on a “thorough literature review” for all target technologies to identify ranges of price points. However, as noted, the literature review was not thorough and contained virtually no peer reviewed publications. The report relied heavily on the NRC study. However, the NRC study is five years old and should have only been the starting point for the research.

The methodology is adequately described. However, it is simplistic and mechanistic and is heavily dependent upon many assumptions. Most of these assumptions appear to be relatively reasonable; some do not.

There is a tendency among researchers – evident in this draft report -- to evaluate technologies under conditions which are best suited to that specific technology. This can be a serious issue in situations where performance is strongly dependent on duty cycle, as is the case for many of the MD/HD technologies evaluated in this report. One result is that the reported performance of a specific technology may be better than what would be achieved by the overall vehicle fleet in actual operation.

Another issue with technologies that are not fully developed is a tendency to underestimate the problems that could emerge as the technology matures to commercial application. This problem is little discussed in the draft report.

Such issues often result in implementation delays as well as a loss of performance compared and increased costs compared with initial projections. As a result of these issues, some of the technologies evaluated in this draft report may be available later than expected, or at a lower level of performance and higher cost than expected. Extensive additional research would be needed to quantify these issues, and regulators will need to allow for them the fact that some technologies may not mature as expected. The draft report should discuss this and related relevant issues.

1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?

Addressed above.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

Most of the price and breakouts presented for the various vehicle technology categories are credible, but minimally so. They are, in general, not adequately supported due to the deficient literature review and inadequate research conducted. They require fixed, and sometimes heroic, assumptions and a lot of faith in the algorithms utilized.

For example, some technologies, such as certain aerodynamic features, automated manual transmissions, and wide-base single low-rolling-resistance tires, are already available in production. On the other hand, some of the technologies discussed in the draft report are in varying stages of development, while others have only been studied using simulation models.

The NRC recommended that regulations should target the final stage vehicle manufacturers, since they have the greatest control over the design of the vehicle and its major subsystems that affect fuel consumption. Component manufacturers will have to provide consistent component performance data. As the components are generally tested at this time, there will be a need for standardized test protocol and safe guards for the confidentiality of the data and information. It may be necessary for the vehicle manufacturers to provide the same level of data to the tier suppliers of the engines, transmissions, after-treatment and hybrid systems.

Simulation modeling should be used with component test data and additional tested inputs from powertrain tests, which could lower the cost and administrative burden yet achieve the needed accuracy of results. The program should represent all the parameters of the vehicle (powertrain, aerodynamics, and tires) and relate fuel consumption to the vehicle task.

A number of the technologies, such as adaptive cruise control, predictive cruise control, and navigation and route optimization are currently being applied by the trucking industry without any regulation because the owners and operators view the reduction in fuel costs as good business. What does this imply for the feasibility and optimality of some of the proposed regulations discussed in the draft report? The report recognize this and discuss the implications.

Detailed Comments on Section 3

P. 9, ¶ 1: “The methodology used here for determining incremental retail prices relies on a thorough literature review for all target technologies to identify ranges of price points. The data reported here draw heavily upon the most recent National Research Council study of medium- and heavy-duty vehicle technologies.”

The NRC study referred to is already more than five years old, the research for the NRC study was conducted six or seven years ago, and the data and sources used in the NRC study are at least 5-10 years old. Some of the references cited in the Tetra Tech draft report are decades old, and in any event, the literature review was not sufficiently “thorough”.

P. 9, ¶ 2: “The ranges of values found in the literature are scaled to project incremental prices using manufacturing volume-dependent cost curves.”

It is not clear what this sentence is supposed to mean.

P. 9, ¶ 4: “Indirect costs are derived from direct costs using an adjusted multiplier.”

Can this adjusted multiplier be quantified and illustrated simply?

P. 9, ¶ 4: “The first main factor is derived from research conducted for the U.S. Environmental Protection Agency (EPA) and reflects manufacturer costs that are difficult to allocate to specific production activities, such as R&D, corporate operations, dealer support, and marketing.”

The references cited are EPA reports, some of which have been known to be incestuous and not necessarily rigorous, objective, or credible. Further, these were not peer-reviewed.

P. 10, ¶ 1: “The relative contributions of each of these elements to the total indirect cost are based on research by Argonne National Laboratory for the U.S. Department of Energy that examined and modified Argonne National Laboratory’s incremental cost components of implementing new vehicle technologies.”

The references cited are DOE lab reports: They are not peer-reviewed and some are decades old.

P. 10, ¶ 2: “The second main factor of the adjusted multiplier reflects improvements in the manufacturing process that take place as the technology matures. As described by the Center for Automotive Research, process efficiencies that are learned over time are captured in this type of cost reduction and are expressed as an annual percent improvement from the previous year.”

How will these be affected (positively or negatively) by the mandated MD/HD fuel efficiency improvements? Was this issue even considered here? If not, why not?

P. 12, ¶ 2: The indirect cost factors and the manufacturing process improvements then are multiplied together to derive the adjusted multipliers that make up the volume-dependent technology cost curves for each of the identified technologies.

This sentence is nearly incomprehensible.

P. 12, ¶ 3: A teardown analysis was not performed in this report to determine the breakout between the direct and indirect cost elements.

Why was not a teardown analysis conducted? The NHTSA standards that will eventually result from the work being reviewed here will be extremely important, will likely cost industry, transportation companies, and consumers hundreds of billions of dollars, and will have very significant impacts on the U.S. economy. Accordingly, appropriate resources, time, and effort should go into developing the standards – including teardown analyses, simulation analyses, pilot programs, etc.

Further, the contractor could have used simulation modeling with component test data and additional tested inputs from powertrain tests that could lower the cost and administrative burden but, at the same time, achieve needed accuracy of results.

Does Tetra Tech (or NHTSA) intend to conduct a pilot program to “test drive” the certification process and validate the regulatory instrument proof of concept? Are any similar programs planned by Tetra Tech or NHTSA?

P. 12, ¶ 4: To estimate the cost element breakouts in the incremental price, the relative cost contributions for truck manufacturers in RTI’s 2010 heavy duty truck report were used.

RTI’s study was conducted five years ago for EPA and was not peer-reviewed. Were any other sources consulted here?

P. 17, Table 10: what is meant by “Vocational?” This should be defined up front.

2. Life Cycle Costs (Section 4)

2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. If not, what can be improved and how?

This section presents information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories that is, perhaps, minimally sufficient. My comments on the deficiencies of the previous section apply here.

NRC recommended that any regulation of MD/HD fuel consumption should use Load Specific Fuel Consumption as the metric and be based on using an average (or typical) payload based on national data representative of the classes and duty cycle of the vehicle. Why is this not discussed in the draft report?

The fundamental engineering metric for measuring the fuel efficiency of a vehicle is fuel consumption -- the amount of fuel used, assuming some standard duty or driving cycle, to deliver a given transportation service, for example, the amount of fuel a vehicle needs to go a mile or the amount of fuel needed to transport a ton of goods a mile. For light-duty vehicles, the CAFE program uses mpg. This measure is not the appropriate measure for MD/HDs, since these vehicles are designed to carry loads in an efficient and timely manner.

The project could have used several actual MD/HD vehicles, including various applications, and developed the approach to component testing data in conjunction with vehicle simulation modeling to derive LSFC data for these vehicles. The actual vehicles could also be tested by appropriate full-scale test procedures to confirm the actual LSFC values and the reductions measured with fuel consumption reduction technologies in order to validate the evaluation method.

Research could have established fuel consumption metrics related to the task associated with a particular type of MD/HD vehicle, and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo carrying capacity. Research is required to determine whether a system of standards for full but lightly loaded (“cubed-out” MD/HD vehicles) can be developed using only the LSFC metric or whether these vehicles need a different metric to properly measure fuel efficiency without compromising vehicle design.

Regulation of MD/HD fuel consumption should use LSFC as the metric and be based on using an average (or typical) payload based on national data representative of the classes and duty cycle of the vehicle. Standards

could require different values of LSFC due to the various functions of the vehicle classes. The draft report should use a common procedure to develop baseline LSFC data for various applications, to determine if separate standards are required for different MD/HD vehicles that have a common function. Data reporting or labeling should state a LSFC value at specified tons of payload.

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

The life cycle cost elements presented are minimally credible. They are not adequately supported. My comments on the deficiencies of the previous section apply here.

When there are several fuel-saving options and complex truck operating conditions, performance standards are likely to be superior to specific technology requirements. Where in the draft report is this discussed?

Increasing vehicle size and weight limits offers potentially significant fuel savings for the entire tractor-trailer combination truck fleet, but this would have to be evaluated against increased costs of road repair. Case studies demonstrate that potential fuel savings of up to 15 percent or more are possible – savings that compare very favorably with most of the technologies discussed in the draft report. Further, these savings are similar in size but independent and cumulative of other actions that may be taken to improve fuel consumption of vehicles; therefore the net potential benefit is substantial. The draft report should discuss what is required to implement these and analyze how the potential fuel savings and other benefits of such liberalization can be realized in a way that maintains safety and minimizes the cost of potential infrastructure changes. This discussion should include issues such as regulatory limits that currently restrict vehicle weight and that freeze LCV operations on the Federal Interstate System, establishing a regulatory structure that assures safety and compatibility with the infrastructure, and changes that would be necessary to permit reasonable access of LCVs to vehicle breakdown yards and major shipping facilities in close proximity to the interstate system.

Intelligent transportation systems enable more efficient use of the existing roadway system by improving traffic flow and reducing or avoiding congestion. This should be discussed in the report.

For example, intelligent vehicle technologies provide fuel consumption reductions by taking advantage of knowledge of the vehicle's location, terrain in the vicinity of the vehicle, congestion, location of leading vehicles, historical traffic data, and other information, and altering the speed of the vehicle, the route the vehicle travels, or, in the case of hybrid electric vehicles, altering the power split ratio. These fuel savings may not show up in fuel consumption tests, and this should be recognized in the analysis.

The report could obtain data on fuel consumption from several representative fleets of MD/HD vehicles. This would provide a real-world reality check on the effectiveness of the proposed regulatory design on the fuel consumption of MD/HD fleets in various parts of the marketplace and in different regions of the country.

Detailed Comments on Section 4

P. 112, ¶ 1: "This section presents the information currently available on the vehicle life cycle impacts of the identified technologies in the various vehicle categories."

There is more information currently available than is included in the draft report.

3. Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

No: In general, this whole section is very weak and needs to be strengthened and expanded. The discussion is basically generic and evidences little serious research or analysis.

Elasticity estimates vary over a wide range, and it is not possible to calculate with very much confidence what the magnitude of the “rebound” effect is for MD/HD vehicles. In medium- and heavy-duty trucking, the “rebound” is a more complex phenomenon and has been studied less than for the light-duty vehicle effect. Thus, it may not be valid to apply the light-duty rebound estimates here.

Standards that differentially affect the capital and operating costs of individual vehicle classes can cause purchase of vehicles that are not optimized for particular operating conditions. The complexity of truck use and the variability of duty cycles increase the probability of these unintended consequences, and the draft report should recognize this.

Some fuel efficiency improving technologies will add weight to vehicles and push those vehicles over federal threshold weights, thereby triggering new operational conditions and affecting, in turn, vehicle purchase decisions. Did the report conduct any research to assess the significance of this potential impact? Further, if the vehicles are getting heavier, what implications does this have for safety?

For example, recent research has found that CAFE regulations have had the unintended consequence of greatly increasing the weight of LD trucks, with negative consequences for safety. Is there the possibility of something similar happening with MD/HD regulations? The draft report should discuss this.

Similarly, if the vehicles are getting heavier, what implications does this have for road and infrastructure impacts?

Certain fuel-saving technologies will add to vehicle weight, affecting operators’ costs in three ways. First, transporting the extra weight itself increases fuel costs, partially offsetting the fuel savings the technologies allow.

Second, in MD truck applications, the extra weight may increase the loaded gross weight of some present Class 2 vehicles to over 10,000 lb. and of some present Class 6 vehicles to over 26,000 lb. Exceeding these weight thresholds will subject companies operating the vehicles to federal and state motor carrier safety regulations. A truck operator who has not previously been subject to these motor carrier safety regulations or to CDL requirements and is considering whether to adopt new vehicles with fuel-saving technologies and higher weight that would trigger the regulations will have several options. The operator may acquire the heavier vehicles and comply with the regulations or specify offsetting weight-saving equipment in order to stay under the threshold, or acquire smaller trucks than previously used – and thus use a larger number of smaller vehicles. Vehicle manufacturers may decide to market new vehicle designs that facilitate the latter

two choices. Any of these choices will increase the operator's truck transportation costs, and the operator will select the one with the least cost.

Third, in heavy-duty operations in which trucks are sometimes loaded to the 80,000-lb. legal gross weight limit that applies on most major U.S. roads, and in operations in which trucks are sometimes loaded to axle weight limits (e.g., refuse haulers, dump trucks), the added weight of some fuel-saving devices (without concomitant vehicle weight-reducing materials) will reduce cargo capacity, increasing average cost per ton-mile and necessitating more vehicle-miles of travel to carry a given quantity of freight. In an operation in which trucks are almost always loaded to the gross weight or axle weight limit, the added cost will be proportional to the loss of payload. For example, the payload of a truck loaded near the 80,000-lb. limit is about 50,000 lb., so an additional 500 lb. of fuel-saving devices would reduce capacity and increase average cost per ton-mile in an application in which trucks are usually loaded to the gross weight limit. The draft report should at least discuss these issues.

Some fuel efficiency improving technologies will reduce cargo capacity for trucks that are currently "weighed-out" and will therefore force additional trucks on the road. What research was conducted here of this potential impact?

Economic analysis of pre-buy and low-buy impacts for some trucks found that the low-buy "dip" was actually more substantial than the pre-buy "peak" and that there was thus a net decrease in sales over this period. A net downturn in sales also indicates that a portion of vehicle owners may be keeping their older units on the road longer (assuming freight demand levels do not decrease substantially). The aggregate impact of all of these factors was estimated to result in a net increase in national annual NO_x emissions, relative to the case without pre-buy/low-buy and elasticity effects. What implications do these findings have for the regulations discussed in the draft report?

The draft report does not adequately address the issue of class shifting. When manufacturers build vehicles, they make trade-offs related to various vehicle attributes in order to produce a vehicle that is most attractive to a given market segment. For example, manufacturers regularly need to balance issues of performance, cost, and fuel efficiency. In cases where regulation incentivizes a certain class of vehicles to meet a fuel efficiency standard at the expense of performance, a potential buyer may choose to purchase a larger class vehicle to offset the performance losses. This behavior leads to less efficient vehicles on the road -- exactly the opposite effect of what the NHTSA efficiency standards are supposed to achieve. This is referred to as "consumer class shifting," and it can also occur if the cost of different vehicle classes is affected disproportionately by the regulations. For example, requiring aerodynamic fairings on all Class 8 vehicles may cause some companies that currently use these vehicles on long-haul operations to choose smaller, less efficient vehicles rather than invest in the fairings. Others, however, will find they will have to add fairings that provide little benefit at high cost. The level of shift depends on how a regulation affects different vehicle classes and the relative costs across classes. The draft report should discuss class shifting issues and their potential significance.

Was any type of economic/payback analysis based on fuel usage by application and different fuel price scenarios conducted? Operating and maintenance should be part of such an analysis.

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

No: Much more research and effort is required here. See my comments above and below.

Numerous indirect effects and unintended consequences associated with regulations designed to reduce fuel consumption in the trucking sector can be important. For example, researchers must consider the following effects: Rate of replacement of older vehicles (fleet turnover impacts), increased ton-miles shipped due to the lower cost of shipping (rebound effect), purchasing one class of vehicle rather than another in response to a regulatory change (vehicle class shifting), environmental co-benefits and costs, congestion, safety, and incremental weight impacts. The report mentions these, but does a very poor job of rigorous analysis and evaluation. This needs to be remedied.

It is often (but not always) the case that fuel efficiency improvements result in reductions of other pollutants as well. For example, new NO_x and PM standards may require additional fuel use and reduce vehicle fuel efficiency. It is more likely that reduced fuel consumption through fuel efficiency technologies in MD/HD vehicles will reduce emissions of criteria pollutants. Thus, efficiency improvements achieved by improved aerodynamics, tire rolling resistance, and weight reductions will translate into lower tailpipe emissions as well. Nevertheless, as discussed below, it cannot simply be assumed (as the draft report apparently does) that fuel efficiency regulations will automatically result in reductions of other pollutants as well.

New regulations designed to increase the fuel efficiency of MD/HD vehicles must also consider potential impacts on vehicle and highway safety. The safety impacts could be of several types. First, new technologies may have specific safety issues associated with them. For example, hybridization will introduce high-voltage electrical equipment into trucks, and operators, service mechanics, and emergency personnel will thus need to be educated about appropriate handling of this equipment. Second, as discussed, the rebound effect may increase overall truck traffic on the road, thereby leading to potentially higher incidences of accidents. Third, some technologies and/or approaches to improving fuel efficiency may actually lead to a safer highway system. Examples include speed reductions, improved driver training, and use of side fairings which may reduce hazards to other vehicles in inclement weather. Fourth, if new technologies diminish the performance of vehicles (e.g., decreased acceleration times), negative safety impacts could occur. Finally, if new technologies or regulations have the effect of increasing payload capacity for trucks, fewer trucks may be in operation, potentially resulting in safety benefits. A detailed assessment is needed on these and related safety aspects – and on the specific regulations, and should be included in the draft report.

Detailed Comments on Section 5

P. 131, ¶ 5: “The issue of how new fuel efficient and emission reduction technologies and regulations will affect new vehicle prices and operating costs -- and the impact on fleet turnover from those cost effects -- is an area that needs further analysis.”

Agreed. But what does this imply for the whole NHTSA project?

P. 132, ¶ 2: “If investment in new technology is seen as cost effective and lowers operating costs,.....”

If this is so, then why is a regulation needed? Maybe, an outreach and information dissemination program would suffice, would be less intrusive, and would be much more cost effective.

P. 132, ¶ 4: “The implementation of technologies to improve fuel efficiency and reduce emissions can result in environmental co-benefits.”

Yes they can, but not necessarily – as noted above. This discussion is confusing and may be simply incorrect. These are regulations to increase vehicle fuel efficiency and are not designed to affect criteria pollutants. Have these benefits already been attributed to the environmental regulations specifically targeting them? Is there a danger of double counting here? EPA has a nasty habit of double counting (sometimes triple counting) environmental benefits in different air and water regulations. NHTSA must avoid such pitfalls if it is to retain its credibility.

P. 132: Rebound effect

It should be noted that the rebound effect may increase overall truck traffic on the road, thereby leading to potentially higher incidences of accidents. Has this, or will it be taken into account?

Also, to the extent the regulation extends beyond the private cost-effective point, the rebound effect will be reversed. This should also be discussed.

P. 132, ¶ 4: “In the 2014-2018 heavy-duty fuel efficiency program, NHTSA chose a rebound effect for single-unit trucks of 15%. For combination tractors, a rebound effect of 5% was chosen. NHTSA applied the light-duty vehicle rebound effect of 10% to the Class 2b&3 trucks.”

As discussed above, in MD/HD trucking, the “rebound” is a more complex phenomenon and has been studied less than the light-duty vehicle effect. Thus, it may not be valid to apply the light-duty rebound estimates here.

P. 133, ¶ 1: “For the purposes of this report/analysis, we present PM-related benefit per ton estimates as a means of monetizing the criteria pollutant co-benefits in the absence of full-scale air quality modeling to capture the full array of co-benefits associated with the technologies.”

Once again, it sounds like Tetra-Tech may be mixing or mis-estimating the combined effects of separate pollution control technologies.²

Point of Clarification

My point here is that potential double counting of environmental benefits resulting from different rules and regulations must be avoided. Fuel efficiency technologies can indeed reduce emissions and can result in various types of environmental co-benefits. However, some of these environmental benefits may result from other current, impending, or planned environmental regulations and should not be

² After submitting final comments, NHTSA requested that the reviewer provide a clarification on this statement. The reviewer’s response has been inserted under *Point of Clarification*.

double (or triple) counted. That is, some of these benefits may be, at least in part, attributable to environmental regulations specifically targeting them.

This is an important point because in the past, EPA has been accused (sometimes appropriately, and sometimes not) of double counting environmental benefits in different air and water regulations. Tetra-Tech and NHTSA must avoid such pitfalls if they are to retain credibility.

P. 133, ¶ 1: “GHG impacts are monetized according to their effects on human health (diarrhea, vector-borne diseases, and cardiovascular and respiratory mortality), property, agricultural productivity, and terrestrial and aquatic ecosystems. Atmospheric GHG concentration influences global temperature and sea level, which in turn affect many complex natural systems. The risks associated with increased GHG concentration include mortality changes, increased flood risk, and decreased productivity due to weather. These risks shown in Table 52 were monetized in the social cost of carbon by the U.S. Government Interagency Working Group on Social Cost of Carbon.”

This paragraph is not credible. There is no scientifically valid relationship between CO₂ and diarrhea, vector borne diseases, etc. CO₂ is necessary for life and for agricultural production, and increased CO₂ increases agricultural productivity. Similarly, there is no empirically proven impact of GHGs on global temperature. The “proof” comes from unvalidated models which are increasingly inaccurate. Remote Sensing System (RSS) data show that there has been no global temperature increase for more than 18 years, despite increasing GHG concentrations. Similar comments pertain to the relationship between GHGs and flood risk, mortality changes, etc.

The IWG SCC estimates in Table 52 of the draft report (which are 50 percent higher than the IWG SCC estimates derived only three years earlier) have been thoroughly discredited. Independent, peer-reviewed evaluation has concluded that the IWG SCC estimates are “useless for policy purposes.” Further, SCC estimates are not accepted by Congress and are being litigated in court and in the states. They are phantom numbers that cannot be used to justify MD/HD regulations.

P. 134, ¶ 2: “Energy security premiums reflect the vulnerability of the U.S. economy to oil supply shocks, price spikes, and import costs. Because energy costs affect all sectors of the economy, U.S. dependence on petroleum imports from potentially unstable sources can have far-reaching effects. Political unrest in the Middle East and price hikes exerted through the near-monopoly power of the Organization of Petroleum Exporting Countries (OPEC), for example, have resulted in high gasoline and diesel prices at the pump.”

This sounds like it could have been written during the “energy crises” of the 1970s. Shale technologies have vastly increased U.S. liquid fuels and natural gas production to the point where the U.S. is becoming the world’s energy superpower. World oil prices have decreased 50% over the past six months, and OPEC is in disarray. The discussion in this section should be revised to reflect recent research and 21st century energy realities. For example, MD/HD regulations that may make sense or be cost effective at oil prices of \$100/bbl. may not with oil at \$50/bbl.

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Organization is acceptable; readability and clarity could be improved. Examples and real-life experiences would help a lot. So also would recognition and incorporation of recent research in various relevant areas, a more comprehensive literature review, and the inclusion of relevant peer-reviewed research.

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

No. Much additional information, research, and data are required – as discussed in my comments.

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

The report contains much useful data and information. However, the applications to derive estimates and conclusions are rote and mechanistic, are often based on questionable assumptions, and require a lot of faith to believe.

4.4 Please provide any other comments you may have on this report.

There may be more effective, less costly, and complementary approaches than vehicle fuel efficiency standards for reducing fuel consumption of MD/HDs, such as training truck drivers on best practices, adjusting size and weight restrictions on trucks, implementing market based instruments (e.g., fuel taxes), providing incentives for mode shifting, or developing intelligent vehicle and highway systems. This report should at least identify and discuss these.

There are a number of approaches for reducing fuel consumption in the trucking sector and there is evidence that several approaches -- particularly driver training and longer combination vehicles (LCVs) -- offer potential fuel savings for the trucking sector that rival the savings available from technology adoption for certain vehicle classes and/or types. The report could analyze these alternatives.

Notably, there are significant opportunities for savings in fuel, equipment, maintenance, and labor when drivers are trained properly. Research indicates that this could be one of the most cost-effective and best ways to reduce fuel consumption and improve the productivity of the MD/HD sector. Cases studies demonstrate potential fuel savings of 2 to 17 percent with appropriately trained drivers -- savings that compare very favorably with those resulting from many of the various technologies discussed in the draft report.

For example, regulations could encourage and incentivize the dissemination of information related to the relationship between driving behavior and fuel savings. One step in this direction could be to establish a curriculum and process for certifying fuel-saving driving techniques as part of commercial driver license certification and to regularly evaluate the effects of such a curriculum.

Research is also required to develop an approach that results in MD/HD fuel efficiency standards that are cost effective and that accurately represent the effects of fuel consumption reducing technologies. This work should recognize that regulations must fit into the engineering and development cycle of the industry and provide meaningful data to vehicle purchasers.

A pilot program is required to “test drive” the certification process and validate the regulatory instrument proof of concept. The program could be structured to obtain experience with certification testing, data gathering, compiling, and reporting. An effort should be made to determine the accuracy and repeatability of all the test methods and simulation strategies that will be used with any proposed regulatory standards and a willingness to remedy problems that are identified. Data on fuel consumption could be obtained from several representative fleets of vehicles. Such research could provide a real world check on the effectiveness of the proposed regulatory design on the fuel consumption of MD/HD fleets in various parts of the marketplace, and in different regions of the country.

The economic merit of integrating different fuel-saving technologies will be an important consideration for operators and owners in choosing whether to implement these technologies. This is not adequately discussed in the draft report.

Since tractor-trailer trucks have relatively high fuel consumption, very high average vehicle miles traveled, and a large share of the total truck market, these should be targeted for fuel efficiency improvements and fuel consumption reductions. Similarly, large trucks account for about 80 percent of total truck fuel consumption. Accordingly, a given percentage reduction in such vehicle categories will save more fuel than a matching percent improvement in other vehicle categories. For example, the potential fuel savings in tractor-trailer trucks represents about half of the total possible fuel savings in all categories of MD/HD vehicles. Nevertheless, while it may be expedient to initially focus on those classes of vehicles with the largest fuel consumption, selectively regulating only certain vehicle classes could lead to unintended consequences and could compromise the intent of the regulation. Within vehicle classes, there may be certain subclasses of vehicles (e.g., fire trucks) that could be exempted from the regulation without creating market distortions. The draft report and any subsequent regulations based on it must incorporate these considerations.

Fuel consumption metrics should be calibrated to the task associated with a particular type of MD/HD vehicle and set targets based on potential improvements in vehicle efficiency and vehicle or trailer changes to increase cargo carrying capacity. Research needs to be conducted to determine whether a system of standards for full but lightly loaded (cubed-out) vehicles can be developed using only the LSFC metric or whether these vehicles need a different metric to accurately measure fuel efficiency without compromising the design of the vehicles. Research is also required to produce an approach that results in fuel efficiency standards that are cost effective and that accurately represent the effects of fuel consumption reducing technologies. Proposed regulations should fit into the engineering and development cycle of the industry and provide meaningful data to vehicle purchasers. The draft report should at least discuss these issues.

As discussed, to the extent that regulations alter the number of shipments and VMT, there will be safety and congestion impacts. A more detailed assessment of these impacts is needed based on the type of regulation discussed in the draft report and that may be implemented by NHTSA.

The technology packages that result in the fuel consumption reduction for each application have anticipated costs. These costs were estimated assuming that the technologies will be produced at large enough volumes to achieve economies of scale in the relevant time frames. Eventually, costs versus benefits will have to be estimated, and there are several ways to do this. One measure, dollars per percent fuel saved, is the cost of the technology package divided by the percent reduction in fuel consumption. Another measure, dollars per gallon saved per year, accounts for the fact that some vehicles are normally driven more miles than others and estimates how much it costs to save one gallon of fuel each year for the life of the vehicle by adopting the relevant technology. A third measure, “breakeven” fuel price, represents the fuel price that would make the present discounted value of the fuel savings equal to the total costs of the technology package applied to the vehicle class. However, the breakeven fuel price may not necessarily reflect how vehicle buyers would evaluate technologies. Because vehicle buyers often do not plan to own the vehicle for a full life, they may use a different discount rate, and they would need to consider operation and maintenance costs, which are excluded from the estimates. However, a lifetime breakeven price is a useful metric for considering both the private and the societal costs and benefits of regulation.

Although incomplete, these measures indicate the differences in economic viability of the various technology options in the draft report for the indicated vehicle classes. However, breakeven prices are calculated assuming all the technologies are applied as a package whereas, in fact, individual fuel-saving technologies applied in a given vehicle class may face much lower or much higher breakeven values than indicated by aggregate figures. While detailed analysis of this issue may be outside of the scope of the draft report, it is important and should at least be mentioned.

There is an inherent conflict between the need to set a uniform test cycle for regulatory purposes and existing industry practices of seeking to minimize fuel consumption of MD/HD vehicles designed for specific routes that may include grades, loads, work tasks, or speeds inconsistent with the regulatory test cycle. This indicates the critical importance of achieving consistency between certification values and real-world results, in order to avoid driving decisions that degrade rather than improve real-world fuel consumption. Regulations can lead to unintended consequences, either because the variability of tasks within a vehicle class is not adequately dealt with or because regulations may lead to distortions between classes in the costs of accomplishing similar tasks. There is little evidence that the draft report has adequately addressed these issues.

More fundamentally, fuel consumption by MD/HD vehicles represents nearly 30 percent of total U.S. liquid transportation fuels and has increased more rapidly -- in both absolute and percentage terms -- than consumption by other sectors, and these trends are forecast to continue. At the same time, over the past two decades MD/HD vehicle fuel efficiency has been increasing by about one percent per year without vehicle regulations. This critical fact is not recognized in the draft report. A one percent annual compounded rate of change is, in the long run, nontrivial and, given the huge volume of fuel consumption is significant. Why has this been occurring in the absence of regulation? How might new MD/HD regulations change this annual rate of fuel efficiency increase? Would the presumed or estimated increase in this rate be worth the time, effort, costs, indirect effects, and unintended consequences of new MD/HD regulations? Might new regulations actually be counterproductive here? All these are important issues that need to be addressed.

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

The report is acceptable with major revisions, as discussed in my comments.

Suggestive List of References That Could be Consulted

(These are meant to be indicative, not comprehensive)

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COMMENTS SUBMITTED BY

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Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emission Reduction Technologies for MY 2019-2022

1. Incremental Cost Analysis (Section 3)

1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.

An extensive literature review was presented in the report's Appendix A although the major information source used was the NRC 2010 report in most cases. Use of a wide range of data sources makes it difficult to assure that the underlying assumptions behind estimates are consistent. For example, the average of low- and mid-values incremental price estimates has been assumed for the incremental price at the lowest production volume. It is likely that the estimates from various sources are not at the same assumed annual production volume of 50,000 besides the fact that the price range in some technology cases has been found to be quite large and the baseline technology assumed to derive the incremental price may not be the same. In addition, estimates used based on a review of various information sources further require that they are truly incremental prices and not costs and in the latter cases an appropriate same scaling factor/multiplier needs to be used. In Appendix A, the term "cost" was used throughout although estimates were used for incremental prices. For the same reasons, the use of word "price" vs "cost" needs to be done appropriately in the report. It is unclear from the report how these important issues were addressed. By taking the average of the range of price estimates to some extent addresses this issue, but a validation of the final estimates in cases where technology has already been commercialized would have been useful. It is unclear, from the individual technology curves starting on pg. 21 of the report, what does the incremental price range shown by the vertical lines at four specific annual production volumes represent including underlying assumptions?

1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

The quality, scope, and rigor of the methodology used to calculate incremental prices have been adequate by making use of the best available resources, primarily from the prior EPA research. A combination of several available methodologies was used to derive the final incremental technology price estimates as a function of annual production volume. The reviewer is unaware of whether this approach has been used in any prior such studies as a proxy to detailed vehicle teardown for an initial retail part price breakdown. No backup calculations such as in the form of spreadsheet files were available to determine accuracies of derived estimates. In addition, the statistical curve fitness values for the derived quadratic relationships were unavailable. An excellent job has been done by providing a step-by-step procedure using the methodology for estimating the incremental retail price sensitivity to annual production volume on p.14-16.

The use of indirect cost factors to estimate the decrease in costs as the cumulative manufacturing volume increases over time is somewhat misnomer since this factor was initially applied to the assumed technology retail *price* besides the fact that one of the two major elements of the incremental price is indirect cost. A

further description of this factor would have been helpful. The cost element breakouts in the incremental price based on 2010 RTI's 2010 heavy duty truck report seem to be reasonable.

It'd be useful to provide the distinction between High 1 and High 2 Technology Complexity cases. Based on ICF listed on Table 2, the cost reduction for High 1 with increasing production volume is higher than for High 2, implying thereby that incremental price will be higher for more complex technology High 2 than High 1. But the estimates shown by developed relationships in Tables 9 thru 11 indicate otherwise.

1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?

The underlying factors and assumptions used in the analysis based on the recent published research seem to be reasonable. Most developed technology incremental price curves showed a reduced marginal price with the increasing production volume, and the price leveling off at annual production volumes beyond 600,000.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

The incremental price and breakouts presented for the various vehicle technology categories seem to be credible and adequately supported. The share of direct vehicle manufacturing cost to the total incremental price increased with the increased production volume as shown in Tables 5 thru 8. Also, the share of direct vehicle manufacturing cost decreased with the increased technology complexity. Validation of price breakouts using a few example technology cases considered would have been useful.

2. Life Cycle Costs (Section 4)

2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. If not, what can be improved and how?

This section completely lacks the currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. Life cycle costs tables were presented by the individual identified technologies but limited to only three cost categories, maintenance, replacement, and residual value. In most cases, estimates were shown as TBD and NNI indicating that the data was unavailable. In a few cases, estimates were shown without providing any reference for the data source used. In addition, fuel savings -- the major component of life cycle costs for fuel efficient technologies is completely missing. There was just a mention of it that fuel savings are determined from SwRI are not being included here.

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

A few life cycle cost elements were only presented and even in those cases have not been credible and adequately supported. Specifically, no fuel savings estimates for various technologies were provided.

3. Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

Most important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emission reduction technologies have been discussed with estimates available in some cases, thereby limited consideration can only be given in the subsequent desired life cycle analyses. It is unclear why energy security premium on Table 51, p. 134-135, would decrease thru the year 2030 initially, followed by a decrease in 2035+.

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

Major elements of the potential cost impacts associated with each of the indirect effects have been only been qualitatively discussed. A further research on how to quantify some of these effects would be useful.

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Overall, the report is well-organized. Since the report is based on a review of extensive literature research, an appropriate discussion of underlying assumptions would strengthen the report quality.

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

In most parts, the information provided in the report is limited to some extent in terms of underlying assumptions. Values selected for incremental prices of various technologies are most cases judgmental, without providing any detailed supporting explanation behind the selection of a particular reference.

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

The problem of estimating incremental prices of medium- and heavy-duty vehicle fuel efficiency and emissions reduction technologies has been addressed really well using a cost-effective approach by drawing upon peer reviewed published studies and data. The report is well-organized in terms of an initial discussion of various cost elements by three major truck application types followed by actual price estimates including its breakdown based on a discussion of actual information source(s) in Appendix A.

Major weakest parts of the report is in Appendix A while discussing supporting data and references data used for a selection of the incremental price range of a technology. The selection rationale in most cases is not

intuitive and a general discussion by each technology and truck application type if included in the main body of the report would be useful. It is very hard now for a reader to decipher the reasons behind the selection of specific incremental technology price range estimate.

4.4 Please provide any other comments you may have on this report.

Additional comments by specific page number of the report have been included at the end of the report.

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

The report is acceptable as is with the exception of quantification of life cycle cost elements and most indirect cost categories necessary for the follow-on life cycle cost analysis. Since the report draws upon reported incremental prices of published studies and data instead of significantly more expensive teardown analysis, some sort of validation in form of case studies and/or available price data for a few of the commercially available technologies would have strengthened the results presented. A summary discussion of incremental price estimates by technology and truck application type in the main body of the report would be useful.

ADDITIONAL COMMENTS

1. p. 13 It is noted that the relative net income increases with increasing technology complexity – not found to be the case in Tables 5 thru 8. The net income share of incremental price was found to be the same in most cases and the transition from High 1 to High 2 Technology Complexity case caused a rather decrease in its share.
2. p. 17-20 (Table 10 & 11): The incremental price of Weight Reduction per unit mass savings is estimated to be the same for Vocational and Line Haul vehicle types. The underlying assumptions behind substitution materials discussed in Appendix C (Vehicle Simulation and Vehicle Technologies) by vehicle type are unclear. Estimates used from Appendix A based on various sources require a validation of underlying assumptions before selecting the appropriate value. It is preferred that the data validation be done in all technology cases.
3. p. 112: Life cycle costs – fuel savings are determined from SwRI are not being included here and thereby provides an incomplete picture of life cycle costs.
4. p. 118 -122: The battery replacement cost of \$455 doesn't seem to vary by truck type although power requirements are most likely to vary to some extent (p.118-119). Similarly, for hybrid electric vehicles on p. 120 and for Cab Insulation to Reduce A/C (p. 122).
5. p. 128: Resale value has been shown only in the case Class 8 6x2 Configuration
6. p. 34 & 35 : no incremental price difference between various truck classes (mainly for Class 2b&3 and Class 4-6) for Cylinder Deactivation, Stoichiometric GDI, Lean Burn GDI with SCR, Turbocharging & Downsizing, Engine Downsizing, Low Friction Engine Oil (D) & (G), Engine Friction Reduction (D) & (G), Air Conditioning Improvements, Cab Insulation Price, Low Resistance Tires, Low Friction Axles & Lubricants, ?

7. p. 99-101: Incremental prices for low resistance tires seems to be too low, particularly \$27-\$30 for Class 8 truck?
8. p. 54: Engine Friction Reduction – prices same for Class 8 & Class 4-6?
9. p. 130- 131: Fleet Turnover Effects as a part of life cycle costs component was limited to a discussion of issues associated with it without any available estimates from the literature.
10. E-1: When a large incremental price range is selected, e.g., \$7,200-\$30,200 for Class 8 Advanced Bottoming Cycle, the average price based on this wide range may be inappropriate. Further investigations in such cases may be necessary for the appropriate value range for consideration in the analysis.
11. p. E-41 – E- 42: Although same information sources indicating no difference in costs between Class 2b&3 Engine Friction Reduction (G) & (D), but a lower cost value was assumed in the latter case. Similar trend was also observed for Class 4-6 Engine Friction Reduction cases as well but in this case no cost difference between Class 4-6 & 8 (D) vehicle type.
12. E-46 – E-47: Difference in cost between (D) and (G) but the same information sources used do not explicitly provide this distinction.
13. E-59 – E-64: It is appropriate to include only those references used for deriving the cost range of hybrid electric vehicle for different types instead of listing the same references in all cases.
14. E-70 – E-75: No cost difference for Air Conditioning Improvements and Cab Insulation to Reduce A/C among three different vehicle types considered. The maxm. range value of \$500 used in this case doesn't appear to be from one of the listed sources.
15. E-93 – E-100: Same information sources used for all vehicle types of Improved Transmissions – but the highest cost range used for Class 8 vehicle type was based on the estimates for Pickup trucks.
16. E-103: Class 4-6 Dual Clutch Automatic – What's the selection basis for the higher end range value of \$3,600 although two of the sources identified to be \$15,000 instead?

COMMENTS SUBMITTED BY

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DTNH22-13-D-00298 – Task Order 0003, Report 2**February 2015*****External Peer Review of Draft Report: “Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022.”******Peer Reviewer- John Fillion*****Peer review response****1. Incremental Cost Analysis (Section 3)**

- 1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.**

Response

The literature review by Tetra Tech appears thorough for the target technologies and the cost estimates appear reasonable for each volume point. The tables and graphs represent a compilation of the cost for each of the target technologies; and the data should represent a valuable reference source for both experts and non-experts that require a working knowledge of the costs for the relevant technologies that might be used for future truck fuel economy improvements. The target technology descriptions in the appendix should be a valuable resource for non-experts working in the area and a useful resource to the experts. While no cost prediction model can be completely accurate, it is expected that the predicted costs, by this report for the target technologies, would be in substantial agreement with the actual measured future costs for the target technologies should they be deployed.

- 1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.**

Response

The methodology used by Tetra Tech is of good quality and scope. Estimating the future cost of technologies not yet deployed cannot be precise. The costs presented appear reasonable and more effort in this area would not bring about much improvement in these cost predictions. Consequently, the cost prediction method is acceptable as is.

1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?**Response**

The factors and assumptions used by Tetra Tech are reasonable as viewed from the career experience and perspective of this peer reviewer.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.**Response**

The tables and graphs from the tables are credible and properly supported. They will be a useful resource for the readers of the report.

2. Life Cycle Costs (Section 4)**2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories? If not, what can be improved and how?****Response**

The term “Life Cycle Costs” is inappropriate for this report. Since this report is fundamentally driven by environmental concern of CO₂ generation, the reader of the report legitimately would expect an environmental definition of the term life cycle. The expectation would be to read a comparison of the CO₂ generation before the deployment of the target technologies compared to the CO₂ generation over the life of the vehicle after the deployment. The report discusses the changes in the maintenance cost of the vehicles over the vehicle life time as a result of deploying the target technologies. The recommendation is to change section 4 title to “Vehicle Life Maintenance Cost”. Using the definition of maintenance cost for this study, the information represents a good compilation of the vehicle life maintenance cost for each of the target technologies. The majority of the technologies were listed as no net increase (NNI) which is logical and what would be expected. The readers of the report will understand that life maintenance costs will have a small effect on the overall cost of the vehicles, with most of the costs associated with increases in battery and tire maintenance cost. With the nomenclature changes suggested this section is acceptable as written.

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.**Response**

The maintenance cost elements are credible and properly documented.

3. Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at

Response

The analysis presents the important indirect effects that may result from the potential technologies deployed to improve fuel economy. The reader will gain the understanding that fleet turnover and rebound are subjects that will be affected by the future decisions. The study is correct in stating more information is needed to quantify the importance of fleet turnover and rebound. The discussion on incremental vehicle weight, manufacturability and product development, maintenance, repair and insurance are useful to the reader in that the discussions raise the awareness of the issues. The reader will also gain the understanding that these issues are relatively minor parts of the overall new technology discussions. The section on potential issues regarding human health effect, environmental co-benefits, and congestion could be deleted with no impact on the quality of the report. The quantitative effects that new technologies will have in these environmental areas is not well understood and the reader of the report will not gain much insight into these issues other than the fact that they are subjects that may be discussed in the future.

There is a glaring omission from the report that might be included in this section, but should be included somewhere in the report; perhaps its own section would be best. A reasonable expectation for the reader of the report is to gain an understanding of the cost-to-benefit ratio for each of the target technologies. Imagine a manager hearing a presentation from his engineers regarding approval to deploy the target technologies in the truck fleet under his direction. He would want to know how much does the target technology cost, how long does it take to deploy, and what is the payback time for the investment. For each target technology there is a fuel economy improvement and a cost. The manager would want to see a chart that says at \$4 per gallon for fuel the payback is so many years, \$6 per gallon a shorter payback, and for \$8 per gallon for fuel an even shorter payback. Perhaps the manager could give this report to his engineers and ask them to use the data in the report to build such a table; however, this is work that Tetra Tech should do and provide to the readers of the report.

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

Response

The report raised the right indirect issues and provides an overview discussion. Actual field data is required to discuss these issues more completely; how to gain such data could be the work of a future study. The cost-to-benefit table mentioned above needs to be included here or elsewhere in the report.

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

Response

The organization, readability and clarity of this report is good. The report will be a valuable resource for both the expert and non-expert in the field of fuel economy improvements. For the expert the report puts in one place useful information that the expert could reference in their own work. For the non-expert the content of the report and the reference literature will allow the reader to become highly conversant in the subject in a relatively short amount of time.

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

Response

The cost data is the area where both the expert and non-expert will gain useful reference information which is the primary strength of the report.

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

Response

The cost data is the strongest part of the report while the discussions on the indirect effects is the weakest. The mention of the business issues regarding fleet turnover and rebound were good and raised the right discussion points. The effort to attribute a portion of the social cost of air pollution to trucks was not credible. The inclusion of a cost-to-benefit table as mentioned above is necessary in order to discuss the target technologies in a reasonable way.

4.4 Please provide any other comments you may have on this report.

Response

The report is a good compilation of the relevant target technologies for truck fuel improvements and a good estimate of their cost. With the inclusion of a cost-to-benefit table a discussion something like the following could take place.

In order to reduce CO₂ emissions, the government is considering increasing fuel economy standards for trucks. In order to improve profitability, truck companies are considering new technologies to increase the fuel economy of their fleets. Improving truck fleet fuel economy is a shared goal for the government and the truck industry. It is recommended that this shared goal be leverage in the rule making process. Today each truck company has an internal policy regarding the payback required to deploy new technology. For example, the policy might be a 1 year payback, at \$4 a gallon for fuel, to deploy a new fuel economy improvement technology. In order to drive the truck companies to increase their take up rate for new fuel economy

technologies the payback policy needs to be changed. If the government could devise a regulation that caused the payback policy to be 3 years at \$6 per gallon fuel cost, for example, there would be a significant increase in the take up rate for new technologies to improve fuel economy and thus reduce CO2 emissions. The government- industry debate could simply be a negotiation of an acceptable payback period for the desired level CO2 reduction.

Complementary to the cost-to-benefit table, it would be useful to have an environmental life cycle study for the target technologies (in addition to maintenance cycle of this report). In this study, the CO2 generated to create and deploy a target technology would be measured and compared to the CO2 saved through its use. Those target technologies that have a net positive CO2 reduction would also have a specific economic payback period. Thus a correlation table could be generated that linked CO2 reduction to a payback period at various fuel costs. Using this approach it is likely that the point would be found where the increased CO2 required to deploy certain target technologies would not have a net CO2 reduction, and thus be counterproductive. It appears that Tetra Tech has sufficient data to make such a correlation study and they should be charged to do so. For truck fleets there is a strong correlation between net cost savings for new fuel economy improvements and net CO2 reduction; intuition suggests that there should be a wise way to leverage this government industry shared goal in the rule making process.

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable.

Response

The cost section is acceptable as is.

The Life Cycle section needs its nomenclature changed to Vehicle Life Maintenance. The technical data is acceptable as is.

For the Indirect Cost section, the human health and environmental co-benefits portion should be deleted.

The inclusion of a cost-to-benefit table, preferably in its own section, needs to be included.

It would also be helpful to have a CO2 based environment life cycle for each of the targeted technologies. The study would be useful - even if done at a low detail level in order to avoid excessive cost and time delays.

With the above changes the report is classified as acceptable with minor revisions.

COMMENTS SUBMITTED BY

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Peer Review Comments – DTNH22-13-D00298 – Task Order 0003, Report 2

Kenneth A. Small

External Peer Review of Draft Report: “Costs of Medium- and Heavy-Duty Vehicle Fuel Efficiency and Emissions Reduction Technologies for MY 2019 – 2022.”

Note: Items from the Peer Review Charge are given in italics. My peer review comments are given in regular type and numbered with a dash, e.g. 1.2-1 is the first comment on charge question 1.2.

1. Incremental Cost Analysis (Section 3)

1.1 *Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.*

This question is outside my area of expertise.

1.2 *Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.*

1.2-1 The approach used does not provide full confidence that the learning through volume, as opposed to learning through time, is accurately understood. This is important because the cost decrease as a function of cumulative volume has a significant effect on any use of this report. But its estimation is indirect: learning rates are specified as functions of time, not volume (Table 4); and only later are converted to functions of cumulative volumes based on assumed annual production volumes. This indirect approach is correctly noted in the report: “The time based short- and long- term indirect cost factors are used to estimate the decrease in costs as the cumulative manufacturing volume increases over time” (p. 10).

The importance of accurately understanding volume-dependent costs is illustrated by the possibility of technologies whose rapid early adoption become self-reinforcing, as cost declines lead to further adoption; versus others whose slow early adoption becomes self-limiting, due to continued high costs. Apparently a model based on the results of this report can indeed capture these effects, but somewhat by accident since the information is originally derived from assumptions about learning over time, not over volume.

1.2-2 The NRC report (Reference 54), relied upon extensively in this report, discusses hydraulic hybrid vehicles at length. Some justification is needed for why such vehicles are not considered here.

1.3 *Are the factors and assumptions used in the analysis reasonable? Why or why not?*

1.3-1 Cost reductions due to learning and cumulative volume are assumed to apply only to indirect costs. Yet it seems likely that direct manufacturing costs would also decline due to learning and cumulative volume. For example, manufacturing process improvements could lower the requirements for labor and materials.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

1.4-1 The text on p. 10 indicates that only the components of indirect cost, rather than their total, is further broken down using the volume-dependent cost contributions of Tables 5-8. If this statement is true, then the time path of overall cost reductions due to learning is represented solely by the three numbers given in Table 4. These numbers appear to be judgmental based on averages over widely varying conditions, and are not an adequate basis for estimating the effects of learning and cumulative production volume.

If the statement on p. 10 is not true, then the actual volume-dependent cost decline is hidden in Tables 5-8. In that case, the brief citation in note 8 (p. 13) is inadequate to support such an important part of the cost methodology.

1.4-2 Figures 1 through 91 constitute the main results, but this is very spare way to present them. This conciseness is no doubt needed to present the large number of technologies considered, but the format makes no distinction between major and minor technologies, and is inadequate for the former. Specifically, it would be valuable to provide more detail for selected technologies that are likely to be important to regulatory design. I suspect one such technology is hybrid electric, due to its very high incremental cost and its popularity for light-duty vehicles. In this case, and probably others, the report needs to summarize the analyses in the cited references, the degree of certainty, the likelihood of the numbers being up to date, and the likelihood of major changes in the technologies and/or their incremental costs that may occur between now and the time regulations would go into effect.

1.4-3 In Figures 1 through 91, I presume the unexplained error bars surrounding the line for total incremental price represent the high and low end of the ranges. This form of presentation uses the same symbols often used to represent statistical measures of uncertainty behind scientific numbers, but there is no corresponding statistical concept here. Rather, it seems that the curve shown is simply the midpoint of the range. Using the midpoint as a best estimate implicitly assumes that the uncertainty surrounding that estimate is symmetric, which in this case would mean that the range limits are equally likely and there are no intermediate cost estimates that are relevant to understanding the uncertainty. It is unlikely that such assumptions are valid. More likely, there is a range of estimates whose distribution might suggest a most likely value different from the midpoint between the two most extreme estimates. I can understand that it is not practical to provide a thorough analysis of the uncertainty in each estimate for these 91 technologies, but it must be possible for some of the more important ones and this is needed for credibility of the resulting numbers. (See also comment 1.4-2.)

2. Life Cycle Costs (Section 4)

2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. If not, what can be improved and how?

2.1-1. It is mostly adequate. See however comment 2.2-1.

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

2.2-1 In Tables 12-48, the actual “residual value” is likely to depend on the form of regulations, and thus may not be predicted by past experience. For example, the note to Table 47 says “Negative residual value represents the lower resale value of a 6x2 tractor when compared to 6x4 tractors.” The problem is that this point of comparison (the price of a used 6x4 tractor) can itself depend on regulations. If regulations directly discourage use of 6x4 tractors, then their price would fall as a result, so this predicted negative residual value might not actually occur. On the other hand, if regulations discourage new 6x4 tractors but do not discourage a firm from purchasing a used 6x4 tractor, the value of such used tractors might be enhanced due to their scarcity, making the negative residual of a 6x2 tractor even larger.

3. Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

3.1-1 The breadth of coverage and understanding of the issues is appropriate and impressive.

3.1-2 A potentially important omitted indirect effect is that on road wear. Changes in number of tires, vehicle weight, and VMT can all affect road wear, and hence road maintenance costs.

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

3.2-1 The discussion on p. 130 of timing of purchases may be taken to imply that acceleration or deceleration of purchases are equally likely. Actually a decision to “delay purchase to get more efficient vehicles (“post-buy”)” is less likely than the opposite because if there had been market demand for those vehicles, they probably would have been produced. This is true unless there are inefficiencies in the vehicle manufacturing market that prevent manufacturers from converging on design changes that would have market demand.

3.2-2 Table 51: The columns in this table do not match in any obvious way the categories in the verbal discussion. Specifically:

(i) “Monopsony” in the table refers to the ability of the United States, as a large player in international oil markets, to influence the world price to its advantage. One effect of the US having monopsony power might be to counter-act the “near-monopoly power” of OPEC, although monopsony power may have an impact on world price even in the absence of such near-monopoly power. In addition, this component of the energy security premium can be viewed as reflecting high oil prices throughout the economy, not just for gasoline and diesel fuel as implied by the wording.

(ii) “Macroeconomic Disruption/Adjustment Costs” in the table refers mainly to the effects of price spikes on overall economic growth. These effects are the results of oil supply shocks from any cause, not just political unrest or OPEC. The point of including them as indirect costs is that they presumably become smaller when oil-based fuels become a smaller part of the economy.

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

4.1-1 Overall the organization is transparent and the text clear, except where noted.

4.1-2 p. 131, experience from 2007 standards: “The peak [in Class 8 Truck Sales in 2006] corresponds to the incremental cost increase for the new standard (around \$10,000 for the 2007 standards).” Presumably this means that the peak coincides with the onset of the new standard, and thus might plausibly be caused by the associated cost of around \$10,000 per vehicle..

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

4.2-1 p. 15: Step e in the example on p. 15 contains an unexplained equation, as well as a grammatically problematic sentence: “A power function formula is used estimate the initial years.” Apparently this means that the transition between the short term multiplier (1 year) and the long-term multiplier (5 years) is a gradual one described by this formula. But no justification is given for such an equation, nor an indication of how the exponent in the formula is chosen. I infer that it is chosen so that after 5 years, the short-term multiplier (1.39) multiplied by the power function equals the long-term multiplier (1.29); but I can’t make the math work out to get the numbers shown.

4.2-2 p. 15: Steps d and g-j of the example introduce “Newness”, a quantity defined nowhere in the report. It is said to be derived from Tables 2-4, but those tables do not contain any entry called “Newness”. Perhaps it refers to the result of applying the learning rates of Table 4 to a given number of years?

4.2-3 Figures 1-91: These figures, showing total incremental price as a function of cumulative volume, are each labeled with an equation, but there is no indication how it is derived.

4.2-4 The text might address whether there is significant potential for inter-modal shifts between trucking and air freight. If so, such shifts might have an effect on economy-wide fuel use opposite to that of shifts between trucking and rail freight.

4.2-5 p. 136 note 22: The reference cited is a secondary one, i.e. not the original source of the statement. The statement attributed to “the NAS committee” actually occurs in the committee’s own report, namely the National Research Council report of Reference 54, p. 153. This committee would be more properly described as a National Research Council committee rather than an NAS committee. (The National Research Council is operated jointly by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.) This authorship is correctly indicated in the citation to Reference 54 (Appendix A) as well as the list of references in Section 6.

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

Strongest part: Extensive collection of engineering studies to estimate and document the costs of adding specific technologies.

Weakest parts: Lack of discussion of the accuracy of and uncertainty surrounding data from the cited references (see comments 1.4-2 and 1.4-3). Lack of rigorous basis for how incremental costs depend on cumulative production volume (see comments 1.2-1 and 1.4-1)

4.4 Please provide any other comments you may have on this report.

4.4-1 p. 132, “Ton-Miles Traveled vs. Rebound”. This discussion is accurate and valuable. It is worth noting here a difference between the rebound effect for trucks and that for cars. With cars, it is reasonable to take vehicle-miles as the variable measuring quantity demanded, which will respond to changes in cost per vehicle-mile. With trucks, cargo ton-miles is the relevant demand-related quantity, and it may respond in a more complex way to changes in cost per truck-mile, since trucking firms have several options for adjusting the mix of vehicles they use in reaction to particular regulatory-induced changes in vehicle costs and characteristics. In particular, if changes in truck design reduce the payload, they might increase rather than reduce price per ton-mile and this would tend to offset the “rebound effect”.

4.4-2 Wording, typos, etc:

p. 130: “rebuild old vehicles and extend its life”

p. 133: “complexity scalability”??

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

(2) Acceptable with major revisions. The major revision is to fully assess the degree of confidence that can be placed in the incremental cost estimates. This requires a deeper discussion of selected technologies, choosing those most likely to be significant in responses to fuel efficiency standards. It also requires analysis of how a most likely value can be derived from the full set of estimates available, not just the highest and lowest estimate. See comments 1.4-2 and 1.4-3. Minor revisions are needed to clarify various unexplained derivations, as detailed in other comments in this peer review.

COMMENTS SUBMITTED BY

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Before digging into the five questions that comprise the scope of this review, several comments are in order:

First, any objective measure of the technologies under review was obscured by the fact that this mandate was to review the cost of the technologies, but not the benefits of those technologies. To that end, the absence of any bang-for-the-buck capability essentially mooted higher level insights that could have been brought to bear regarding end user payback timing and the impact of that timing on the commercial vehicle demand cycle.

Second, while the costs of the technologies and the incremental manufacturing costs were estimated in detail across a matrix of manufacturing outputs, very little in the analysis considered the product's end users - truckers. The very short timeline of the 2004-2010 EPA regulatory push to clean up NOx and particulate matter suggests that end-user behavior has received the short shrift in the impact analysis of mandates. For a comparable progression of technologies and associated costs, European regulators took an additional three years to go from Euro 4 in 2005 to Euro 6 in 2014.

Since the end of the massive prebuy of equipment in 2006 ahead of EPA'07, there has been a meaningful increase in the chronological age of the total Class 8 fleet in the U.S., from 8.7 years in 2006 to 9.9 years at the end of 2014 (ACT Research data). Perhaps it is coincidental, rather than causal, but it is worth noting that since 2008, the point at which fleet age rose substantively, there has been virtually no change in the number, or rate, of heavy truck related fatalities on U.S. roadways following a long stretch of continuous improvement.

Third, and to the point mentioned above, regulations in the U.S. tend to be "stick," rather than "carrot" based. In the heavy-duty market, EPA'04 and EPA'07 are examples of mandates that raised the cost of vehicles with no usage-based payback for the end user. Adding insult to injury, truckers who were required to purchase technologies that provided no operational payback and raised maintenance costs were also taxed for the privilege of paying more (Federal Excise Tax [FET] + State). So, the tractor sleeper that in 2002 was an estimated \$95,000 + 20% tax (FET @ 12%, state @ ~8%) vehicle is, after EPA'04, '07, '10, Advanced On-Board Diagnostics (AOBD), and Corporate Average Fuel Economy (CAFÉ) '14 a nearly \$130,000 + 20% tax vehicle today. That jump in vehicle cost raised truckers' tax burden by \$7,000. While some of that higher cost is related to commodity costs, and certainly some increment for margin preservation on the part of the truck manufacturers (OEMs), it is not a stretch to suggest that the vast majority of the price increase and subsequent increase in the new truck buyer's tax burden is directly related to regulation. In a word, punitive.

While the desire for cleaner air is applauded, it seems to this reviewer that the objective should be to encourage truckers to buy new trucks, rather than to hold on to their old trucks longer. While it is recognized that different departments have different mandates and different authorities, getting Congress into the act could pay substantive dividends if cleaner air is the desired outcome: A phasing out of the 12% FET on new truck purchases, replaced with a revenue neutral (or even revenue positive) increase in diesel fuel tax, would reinforce the desired behavior by making new trucks more affordable to purchase and older trucks more expensive to operate.

Finally, of the 40 technology options offered, natural gas as an alternative, cleaner burning fuel did not crack the list as a technological solution. While not a chemist, and recognizing that natural gas is a carbon based fuel, it has nevertheless been this reviewer's assumption that natural gas was a cleaner alternative to diesel

with half the carbon of diesel - at least at the molecular level. All the more shocking in the absence of a natural gas option was that Hybrid Electric Vehicles (HEVs) were a considered solution, especially with the knowledge that coal and natural gas will most often be the sources of electricity generation.

1. Incremental Cost Analysis (Section 3)

1.1 Ranges of price points for the target technologies were identified using a literature review. Do the published studies and data cited include all key relevant data sources for the target technologies? Please describe any key sources that are not included this section and explain why they would be helpful.

As costing models are not this reviewer's area of expertise, I am not aware that there are any relevant data sources that were overlooked in the literature review of the analysis.

That said, one obvious shortfall in the costing data is a lack of real-world pricing across all currently existing products. Tire pricing in tables 67-69 are just one example. Relying on studies rather than real-world data for existing products seems a bit sloppy given the importance of this regulation. Calling on companies is hard work. On the other hand, going to tirerack.com is not particularly arduous and you can get real-world pricing in real-time across a range of products. Heavily leaning on a study done back in 2002 (reference 28), and some even earlier studies, for an array of technology pricing comes off as not trying very hard.

1.2 Please comment on the quality, scope, and rigor of the methodology used to calculate the incremental retail prices. Is the methodology clearly described and appropriate to the goals of the analysis? Is it sufficiently comprehensive and robust to provide credible results? Please describe any ways you think the methodology could be improved.

In reviewing technology pricing, I tended to focus on those technologies related to heavy trucks (this reviewer's specialty) as well as those technologies with extreme gaps in pricing estimates. The problem this reviewer saw with many of the technologies with large pricing discrepancies was oftentimes a lack of rigor in checking the results and making sure that what was being considered would fall under the heading "apples to apples." Several examples follow.

Per the last paragraph in response to question 1.1 above, a second major shortcoming that could also be classified as a lack of rigor, or perhaps inadequate methodology, was the lack of real world pricing for existing products. A week of phone calls and a couple days on the internet could have gone a long way to more relevantly bracketing actual pricing, rather than relying on old reports and inflation adjusting decade-old pricing estimates.

In the case of Classes 2b & 3 Cylinder Deactivation (G) (table 10 & 11), the side note in reference 54 indicates that the low price estimate (\$75) is not an apples to apples comparison, and a mid-point of the side note would be ~\$300, suggesting a still wide, but closer incremental price gap. So, why was an outlier included in the table, or why wasn't the data properly adjusted?

There was an excellent sample of supplier pricing for Auxiliary Power Units (APUs) (tables 42-43). However, pricing data for Low Rolling Resistance (LRR) tires (table 68) was not supplier based and not clearly laid out: Class 8 units, or Class 8 and trailer combo? When the tractor/tractor-trailer denominator wasn't specified (as

it was in table 69 examples), it was assumed the references were tractor-only. In the case of LRR tires (table 68), the cost is given as an increase of \$25-\$35 per tire, but in 3 of the 5 references, system cost was put at \$550 (tires only). Given that a traditionally spec'd Class 8 tractor comes equipped with 10 tires, that math works to \$55 per wheel. And again, with tires, there are any number of tire sellers on the web providing comparative pricing across a range of tire types and brands.

For wide-single tires (table 69), the low-end estimate of \$90 from citation 80 appears to be an outlier. The other estimates suggest citation 80 should have been measured as per axle, rather than as a tandem cost: In the other citations, the prices range from a \$140-\$150 upcharge in references 7 and 42, \$175 in references 28, and \$225 in reference 54. Again, not hard to check.

As a final example suggesting that the effort put into the technology pricing section of the report lacked rigor, the Class 8 Reduced Aftertreatment Backpressure (Table 35) serves as an example: Only 2 of 10 citations addressed diesel engines, and one of those two citations, adding a Selective Catalytic Reduction (SCR) system (reference 54, cite 2), is the de facto standard in heavy truck engines today. This effectively leaves one citation for the incremental price estimate.

Given the relative ease in finding some fairly substantive deficiencies in the pricing data, there are significant questions raised regarding the effort expended in finding the best pricing data available. Per the examples presented under question 1.2 in regard to the pricing data, there was a clear lack of rigor in chasing down real-world pricing, a failure to make sure citation comparisons were apples to apples, and the use of citations that don't specifically address the technology in question. Finally, to that I would add the heavy reliance on reference 28 as a pricing guide: While reference 28 undoubtedly cites a great report, I suspect it was even more relevant when it was compiled in 2002.

1.3 Are the factors and assumptions used in the analysis reasonable? Why or why not?

Per previous comments, pricing analysis is not a part of this reviewer's background. However, a lack of real world pricing and a reliance on some very old analysis (even after adjusting for inflation), and in some cases what is perceived as sloppy math, or at a minimum vague citation, leaves one wanting a higher level of diligence.

1.4 Are the incremental price and breakouts presented for the various vehicle technology categories credible and adequately supported? Describe any findings that are not sufficiently supported.

While there appear to be good levels of supporting documentation, the disparate conclusions drawn on pricing suggest that not all of the supporting documentation answers the same question. This phenomenon is illustrated in the very first technology presented in Table 1, the "Class 8 Advanced Bottoming Cycle." The cost estimates range from somewhere between \$7,200 and \$30,200. Obviously, a better understanding of the cost and maintenance of adding a waste-heat capture system is needed: At \$7,200, advanced bottoming is an expensive solution and will disrupt the demand cycle pre and post mandate, but with a healthy boost to fuel economy, say 10%, there is a visible path to payback. At \$30,200, we are talking about a mandate so expensive that even with a robust fuel economy payback, commercial vehicle production for the United States, after a massive prebuy in front of the mandate, would be all but shut down for multiple years post-mandate and truckers would focus their efforts on maintaining existing fleets.

Based on ACT Research analysis, in the \$7,200 and \$30,200 examples above, both with 10% fuel economy gains, the period to payback in the first example for a fleet running 90,000 miles/year would be a not-unreasonable 28 months. In the second example, payback is at an illusory 110 months.

There are other high dollar technologies with wide variance in the cost estimates. Class 8 diesel APUs are a good example, with prices ranging from \$6,000 to \$12,000. Again, the wide price disparity suggests two different outcomes in terms of market acceptance and impact on the demand cycle for Class 8 units. Additionally, one company under reference 54 differentiates their price to include Diesel Particulate Filters (DPFs) and an additional \$3,000 for the California market, raising the question regarding the rest of the estimates: are DPFs included or not? If DPFs are not included, perhaps the range for DPF costs needs to be set higher by \$3,000. *And, to the extent that a large portion of the fleet travels to California, California Air Resources Board (CARB) regulations, especially for the long-haul over-the-road market essentially become de facto rules for national carriers, so should be considered in any discussion regarding the heavy truck market.*

Hewing back to Hybrid Electric Vehicles (HEVs) in tables 40 through 41, with pricing estimates ranging from \$9,000 to \$50,000 from the low end of Class 2 to the high end of Class 8, these are the kinds of solutions that will put demand on hold, cause tradespeople and truckers to drive older equipment, and by extension make the roads less safe for all. Additionally, in the case of Class 8, where something like half of the loads weigh-out, the addition of sufficient batteries would eliminate payload, causing a greater need for trucks to do the same amount of work.

2. Life Cycle Costs (Section 4)

2.1 Does this section adequately present currently available information on the vehicle life cycle impacts of the identified technologies in the various vehicle categories. If not, what can be improved and how?

As I am not a trucker, leasing company, OEM, or parts supplier, my qualification to answer questions regarding life-cycle costs are limited.

That said, given that there are 37 tables (numbered 12 to 48) under Section 4 of the base report on life cycle costs, and only one paragraph touching on methodology/providing any explanation at the start of the section, there is absolutely no support/justification for the maintenance and replacement conclusions reached throughout this section.

And again, getting to the level of diligence in the technology report broadly, for most technologies, “To Be Determined” (TBD) is a favored choice for maintenance, and NNI (No Net Increase) is liberally used under the replacement cost heading. It is hard to believe that the addition of a variable displacement pump (Table 13), for example, will have “NNI” for maintenance or replacement, especially given an “n/a” life cycle interval, or that a system that might add \$30,200 to the cost of a vehicle, Class 8 Advanced Bottoming Cycle (Table 12), would have “NNI” replacement cost and an “NNI” residual value at the end of first owner life (which is also not quantified).

2.2 Are the life cycle cost elements presented credible and adequately supported? Describe any elements that are not sufficiently supported.

Comments pertaining to question 2.1 apply to this question as well: The life cycle cost elements are presented, but they are not supported with commentary or any description of how estimates were derived. Additionally, there is not a consistent standard for measuring changes in maintenance costs: In some cases it is cents per mile, in others it is on a percentage basis (but without a baseline from which to derive cost in cents per mile).

Using Table 12, the first table in the section, as an example, how was the \$0.003 cents per mile increase in maintenance for Class 8 Advanced Bottoming Cycle derived? Given the inherent number of parts in a system that could add up to \$30,000 to the cost of a Class 8 truck, can we believe that annual maintenance over 100,000 miles will only be \$300? Further, does that maintenance number include any ancillary costs for disposal/storage of the steam generating fluids? While not discussed, are these fluids inert, and will truckers' maintenance shops require special training for their handling? [Note that the Appendix, Table 1, citations 7, 58, and 60 all mention steam, suggesting that a fluid is a part of the solution.]

Similarly, in Table 14 on Variable Valve Actuation a 10% increase in maintenance is cited: In Table 12, the measure was cents per mile. Now, we have arrived at a 10% increase at 100,000 miles. What does 10% represent in terms of cost?

As a final example, in Table 23 on Stop/Start, the table shows that brake wear will drop 5% over 45,000 miles, but a \$455 battery will be required at 100,000 miles. Factoring for the net impact is impossible with the data provided. Additionally, there is no background on how the 5% brake wear savings over 45,000 miles was derived.

3. Indirect Effects (Section 5)

3.1 Does the analysis described in Section 5 cover all important indirect effects that may occur at the community- and economy-wide level as a result of adoption of fuel efficiency and emissions reduction technologies? If not, what should be added and why?

One thing that was not apparent in this section, nor anywhere in the document, was a recognition by the writers that the goal of the regulation should be the biggest bang in fuel economy/greenhouse gas reduction for the fewest bucks and that a cost-benefit analysis should be applied to regulation to ensure that buyers of equipment are encouraged, rather than dissuaded from upgrading their fleets. This is especially true if the purpose of the regulation is to facilitate clean air, rather than to change truckers' buying habits as was acknowledged in the first sentence of the second paragraph on page 130, "... reduced operating costs can potentially affect the turnover of vehicle fleets." The only misstatement in that snippet is the word "potentially." Changes in operating costs have and do impact truckers' buying decisions.

Along those lines, and acknowledging the business cycle as a facilitator of buying behavior in 2006-2007, the sentences indicating that the run-up in sales in 2006 "may be partially attributable..." and the falloff in sales in 2007 "may be partially attributable..." are wrong: While the size of the prebuy ahead of EPA'07 is debatable (was it 80,000 or 90,000 units?), there is no "may be" in fact that a prebuy occurred. Whether looking at order, backlog, or production data from the period, medium duty (MD) and heavy duty (HD) truck

buyers overbought trucks starting in 2005 and through 2006 to initially avoid a punitive mandate that raised costs and tax liabilities, increased vehicle complexity, and by extension maintenance. Neither the sharp rise in demand in 2006, nor the sharp plunge in 2007 is justified by macroeconomic data: Given that the economy was strong through 2006, why did order activity collapse in late Q2'06? And with little difference in late 2006-early 2007 GDP (Q4'06, GDP was 3.2% (Q/Q SAAR), while in Q2'07, GDP was 3.1%), why did sales collapse so dramatically in 1H'07? For all of 2007, the ATA's Truck Tonnage Index fell 1% from 2006, but U.S. Class 8 build and sales volumes fell by 55% and 46%, respectively.

Given the gross "may be" misstatement of the situation in 2006-2007, a history lesson to correct the public record follows:

Not only did trucker have the willingness to initially avoid the technology, because a mandate with no payback for the equipment buyer hit at the top of truckers' profit cycle, they also had the ability to avoid the technology. The attached two years of data, from September 2005 through August 2007 and gathered by ACT Research Co., definitively show the impact of the EPA'07 mandate on demand in 2006 and 2007:

As well, the data suggest that a major prebuy was narrowly missed ahead of the EPA'04 mandate, the timing of which was accelerated by the engine manufacturers' Consent Decree by five quarters. But for the fact that credit was essentially unavailable, used equipment prices were at worst in history levels, trucker profitability was also at worst-ever lows, and there was generally complacency amongst the Class 8 trucking community towards EPA mandates, there would have been a fairly large prebuy – again for a mandate with no path to payback: a significantly higher new truck price, *reduced fuel economy*, and increased maintenance costs. While there was a willingness on the part of truckers, worst-ever market conditions meant that the ability to buy was missing. While the prebuy is not visible at an annual level, it can clearly be seen in the monthly data:

	US	US	US	US
	CL8 TOTAL	CL8 TOTAL	CL8 TOTAL	CL8 TOTAL
	<u>NetOrds</u>	<u>Backlog</u>	<u>Build</u>	<u>RSales</u>
Sep. 2005	18,564	134,867	23,516	22,036
Oct.	21,375	131,754	24,972	22,776
Nov.	24,504	135,951	20,799	21,231
Dec.	30,249	147,604	18,940	23,738
Jan. 2006	34,764	158,622	23,784	19,758
Feb.	32,916	167,066	23,070	20,891
Mar.	39,536	180,488	25,736	26,477
Apr.	21,627	177,944	22,887	24,718
May	20,031	170,805	26,814	25,590
Jun.	13,911	163,645	21,811	25,705
Jul.	10,637	148,669	23,628	22,504
Aug.	13,205	130,267	28,070	24,255
Sep.	8,436	112,495	25,989	23,879
Oct.	11,689	95,170	29,083	25,545
Nov.	13,311	82,424	26,054	23,241
Dec.	12,675	76,716	19,254	27,093
Jan. 2007	5,033	61,804	21,184	19,250
Feb.	6,965	51,873	16,915	17,072
Mar.	8,215	44,031	15,834	16,763
Apr.	6,076	41,576	8,456	13,902
May	8,897	42,064	7,998	12,576
Jun.	7,534	40,438	8,775	11,010
Jul.	10,170	41,048	7,493	10,541
Aug.	9,347	40,270	9,411	10,288

For a period of seven months, November 2001 to May 2002, U.S. Class 8 orders (trucks and tractors) were more than double the seven month periods immediately preceding and following:

USC8 net orders	Units (Avg./Mo.)
April'01 - October'01	7,500
November'01 – May'02	16,100 (+147%)
June'02 – December'02	6,800 (-58%)

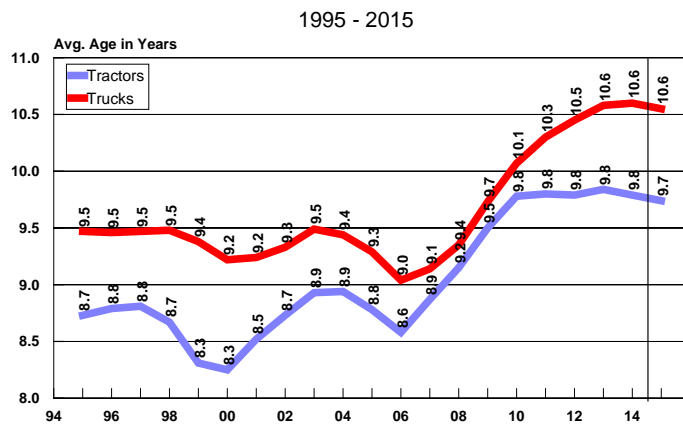
Build activity was not as condensed as orders, but nearly so. In the eight months covering the build ramp, production was over 50% higher than in the preceding eight month period, with a Rorschach-like trough period post mandate:

USC8 Build	Units (Avg./Mo.)
July'01 - February'02	9,100
March'02 – October'02	14,100 (+54%)
November'02 – January'03	9,600 (-32%)

The two examples of prebuy, one large and one small, occurred when truckers' costs outweighed the benefits derived by the technology. Likewise, there was no prebuy ahead of EPA regulations in 1988, 1991, 1994, 1998, or 2010, nor in the face of the CAFE'14 mandate. As mentioned in this review's opening comments, the sharp rise in new Class 8 truck prices, with no path to payback, has caused a sharp rise in overall fleet age in the United States as truckers have had to keep trucks longer to justify new vehicle costs. Also noted was the fact that since 2008, what had been an extended period of falling heavy truck related highway fatality rates, has basically been stalled since 2009.

Regarding the rest of section 5, there is a sense in reading under the Ton-Miles Travel and Rebound piece of the section that very little real-world knowledge was considered:

U.S. Class 8 Population Model Outputs: Average Age, TOTAL Population



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- Because shipping costs are so high, and until recently, fuel costs as well, there has been a concerted effort amongst shippers and truckers to rein in mileage. Owing to sharply higher transportation costs brought about by driver wages, oil prices and equipment costs, starting around 2006 there has been a concerted effort by shippers to increase freight density through package and product redesign.
- It is my experience that freight rates fall when there is too much capacity relative to freight demand. Changes in operating costs brought about by emissions mandates up or down don't change that math. As an example: Even as operating costs went up post 2007, because truckers bought so many trucks in 2006, freight rates fell. Similarly, and in regard to modal comments, what typically happens when trucking prices rise is that intermodal prices follow.
- A comment in paragraph 2 on page 132 was especially disappointing to read, considering that most Americans have seen wages stagnate over the past ~15 years. To paraphrase and take the inverse of the statement, if transportation costs more, consumers won't be able to buy as much. It would seem to me that making transportation cost more in the U.S. makes it more likely that goods are manufactured in countries with lower emissions standards and end up being transported even greater distances. Not only elitist, but irrational as well!

- Once again, this brings us back to the notion that a successful emissions mandate is one that improves emissions and is close to operating cost neutral as possible.

Regarding the commentary on petroleum in section 5, it was obviously not only written prior to the recent decline in oil prices, but the comments suggest it was written prior to hydraulic fracturing revolutionizing domestic energy output starting around 2008. If “energy security” is a pressing concern (it was mentioned twice in a generally brief petroleum commentary), I reiterate my surprise that natural gas was not one of the technological avenues considered in this regulation.

Regarding the commentary on the healthy benefits of regulation (Tables 49 and 50), there were no mentions of the purpose of the discount rate, or why 3% and 7% were chosen. While one would assume the 3% and 7% choices were to represent government and business related cost adjustments, this is certainly not clear from the reading.

3.2 Does this section adequately describe the potential cost impacts associated with each of the indirect effects presented (fleet turnover; rebound; human health and environmental co-benefits; congestion; incremental vehicle weight; manufacturability and product development; and maintenance, repair, and insurance costs)? Describe any ways in which this section could be improved, as well as any additional key relevant published data that should be included.

The answer to question 3.1 gets to the heart of the revisionist history presented in this section and problems with the concept of rebound, the lack of awareness with what has been happening in the energy sector over the past ~decade regarding rebound, and the lack of “back story” on the section on pollution costs that was lost without reading the 7 citations in that section. Again, some rationale behind the chosen discount rates would have been helpful.

Given there were only a couple of paragraphs each tackling the complex subjects of congestion and incremental weight effects, those sections got the point across that choices in a complex system have consequences.

4. General Comments

4.1 Describe your overall assessment of the organization, readability, and clarity of this report, including any changes needed.

The reports were readable and the organization of the supporting documentation was consistent throughout. So, they are fine as is. However, as the question was asked, following are a couple of thoughts:

The layout of the document was arranged by technology, rather than by vehicle type. This made the reading of the documentation, in this reviewer’s opinion, more challenging as more flipping through the material was required to look at the technologies as they impacted the light, medium, and heavy-duty market segments separately.

To that end, because the buyers, vocations, mileage, speeds, etc. are so different when analyzing the different markets, it is this reviewer’s opinion that the reports would have been more informative had they been segmented by duty.

4.2 Is the information provided in the report sufficiently detailed to thoroughly document all essential elements of the cost analysis? If not, what additional information is needed?

As stated in the preamble to the Peer Review Charge questions, it is difficult to examine the value of any technology without an understanding of the benefits of the technology to the desired goal of the regulation.

And as the answers to questions 1, 2, and 3 suggest, there was a decided lack of rigor found in both the incremental and life cycle cost sections, to include a lack of real-world pricing when applicable, pricing references that were not always apples-to-apples, a lack of documentation with regard to the life-cycle cost section as well as inconsistent cost estimates (US\$ versus %). Finally, there were a number of subject headers under section 5 that suggest the analysis was “dialed in”: The conclusions in the history portion of the indirect effect section were inaccurate, and the commentary on petroleum was accurate in 2009, but requires some updating to reflect changes in oil sourcing that have occurred.

What is needed?

In term of the costing section, a detailed review of each technology, to include the use of the phone and the internet where products are actually available in the market. See previous comments on tires.

For the life cycle cost section, we could start with the definition of “end of first-owner life.” As mentioned, a consistent dollars and cents based metric would provide more meaningful comparisons than “5%.” Also, with so many n/a, TBD, and NNI responses, there were virtually no meaningful takeaways from this section. To that end, some discussion of methodology when prices were there, and some reasons why other cells were essentially left blank would be in order.

For section 5, I provided ACT Research data to show, definitively, that there was a prebuy ahead of EPA’07 in 2006 and even a very small prebuy action ahead of EPA’04 through the middle of 2002. I believe words like “probably” and phrases like “may be partially attributable” at a minimum need to be struck from the text, if not replaced by more accurate words like “absolutely” and phrases like “definitely contributed to.”

4.3 What are the strongest and weakest parts of this report? How can the weakest parts of the report be strengthened?

If we were grading on volume, I would give the report an A. Considering this peer review group was tasked with only reading one portion of the report, our section was still a hefty 141 pages, complete with 120 page appendix. Unfortunately, “big” does not mean “good.”

This question comes-off as redundant to the second part of question 4.2. So, to paraphrase the paraphrasing:

Section 1 (and appendix): Inconsistent. Used very old studies for pricing guidance. In some cases, pricing was not apples to apples.

Section 4: The vast majority of the 37 tables had more n/a, TBD, and NNI, than answers. A brief paragraph per table regarding conclusions (or lack thereof) would have been helpful.

4.4 Please provide any other comments you may have on this report.

I prefaced my comments stating that the best outcomes are those derived from the harvesting of the lowest hanging fruit, where there is buy-in from the most important constituency, truck buyers. The rapid adoption of CAFE'14 compliant vehicles, which deliver bang-for-the-buck operating cost improvements, are a great example of the intersection of goals of regulators and truckers. What we saw ahead of EPA'06 provides an inverse example.

Importantly, and to that end, technology cost impacts are often non-linear. In this report, many of the methodologies and projections are based on linear models and presumed effects. Simple and easy to understand, linear models often work well, especially with small delta events. Major costs moves on the other hand, especially when accompanied by no avenue to payback for equipment buyers, or mandate five-figure disruptive technologies, can have non-linear outcomes with exponentially adverse impacts. A technology that carries a big five-figure cost will trigger a distortive prebuy and cause truckers to maintain existing equipment longer, thereby defeating environmental objectives.

5. Overall Recommendation

5.1 Based upon your review, indicate whether you find the report: (1) acceptable as is, (2) acceptable with minor revisions, (3) acceptable with major revisions, or (4) not acceptable. Please justify your recommendation. If you find the report acceptable with minor or major revisions, be sure to describe the revisions needed.

Based upon my review, I would assign a grade of 3 to the report. While the structure is adequate, there are significant shortfalls in execution. A listing of those shortfalls follows:

The technology cost estimate section needs to be gone through with a fine-toothed comb to clean-up inaccuracies, and for those products that are available today, pricing should be accessed from vendors, either by phone or over the internet.

For the life cycle cost section, there needs to be better documentation of how maintenance, replacement, and residual values were derived (or not).

There needs to be a good look through the document to clean up ambiguities:

Table 2: Define short and long term

Tables 49-50: Why those discount rates

The parts of section 5 regarding energy, were written before North America became a juggernaut in global energy markets

The portion of the report discussing the history of regulatory impacts in regard to impacting heavy truck demand, entitled Fleet Turnover Effects, soft sells the impact of regulatory costs on demand and does not address the adverse non-linear impacts of high-cost regulations.