THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

Issues Related to the Center for Automotive Research (CAR) December 15, 2010 Slide Presentation Entitled "The U.S. Auto Industry and the Market of 2025"

March 9, 2011

The International Council on Clean Transportation (ICCT), with the assistance of Dan Meszler of Meszler Engineering Services, has reviewed the December 15, 2010 slide presentation entitled "The U.S. Auto Industry and the Market of 2025," as prepared by the Center for Automotive Research (CAR). The following review is limited to the slide presentation alone as, to the best of our knowledge, there is no supporting report. As a result, in many instances the presented material was analyzed with an incomplete understanding of the methodologies used by CAR to arrive at the presented material. It is unlikely that the review suffers in any significant way from this limitation, but it is possible that incompletely documented statements may have been misinterpreted.

The initial section of this memorandum presents a summary of the findings. Following that are detailed comments that led to the development of the summary, with comments formatted to match each specific page of the CAR slide presentation. This will allow the interested reader to compare ICCT's comments to the CAR presentation on a page-by-page basis.

ICCT has not attempted to produce a "counter-analysis". Instead, data from recent publicly available alternative analysis is used to illustrate the magnitude of potential concerns.

Summary of Concerns

In general, there are two types of issues associated with the CAR presentation. First, there are a number of "factual" errors, where we believe that CAR has misinterpreted or misused data. We do not believe these are issues of opinion, but rather wrong uses of data. It is important to note that such errors appear to be sufficiently significant in the CAR analysis such that their correction would actually "swing" the analysis results to a demonstration of positive CAFE impacts -- even for the CAR-defined CAFE scenarios -- *without any change to CAR's technology benefit and cost assumptions*.

Second, the ICCT has also identified a number of "interpretive" type issues related to whether CAR is either using the most appropriate data, or data in the most appropriate manner. These are more opinion-oriented and generally deal with future or macroscopic conditions that can never be known with absolute precision. Nevertheless, we feel that there are many instances where CAR appears to have relied on data or assumptions that lie quite a distance from a "most likely" scenario.

A summary of our findings is as follows:

Factual Errors:

1) CAR incorrectly treats fuel *consumption* reductions as fuel *economy* increases. These are reciprocal measures that have a major effect on CAR's estimated potential for fuel economy increase and associated CAFE compliance costs.
2) CAR incorrectly aggregates fuel economy impacts across technology pathways. Although this issue is alleviated to some extent by the improper treatment of fuel consumption as fuel economy, it still results in significant overestimation of the relative benefits of PHEV and EV technology to overall fleet average fuel economy.
3) CAR incorrectly interprets the potential 2025 CAFE targets included in the EPA's 2010 regulatory Notice of Intent related to 2017-2025 greenhouse gas (GHG) and CAFE standards. This is due to a failure to properly distinguish the CAFE standard differential associated with greenhouse gas credits for vehicle air conditioning systems. The net effect is that the CAFE scenario that CAR equates to EPA's 6 percent 2025 option is actually closer to a 7 percent option and thus overstates costs significantly.
4) CAR incorrectly includes the potential cost of future safety equipment in an analysis of CAFE impacts. Both CAFE and safety rulemakings require appropriate cost benefit analysis. At a minimum, if CAR wishes to combine such analyses then they must include a benefit analysis for the additional safety equipment, which CAR failed to address.
5) CAR fails to apply an in-use adjustment factor to their estimated CAFE fuel economy data when estimating fuel savings benefits. This results in at least a 20 percent underestimation of fuel savings.
6) Although not a critical issue once other factual issues with the CAR analysis are corrected, CAR has also significantly under-represented PHEV and EV CAFE fuel economy for CAFE purposes. For CAFE compliance under NHTSA only the petroleum consumption is counted and the equivalent electrical energy use is ignored. For GHG compliance under EPA, charge-depleting operation is treated as zero carbon emissions. The respective CAR-estimated fuel economy multipliers of 2.44 and 7 for these technologies should more appropriately be about 3.5 and 12.
7) CAR incorrectly assumes a VMT elasticity that is dependent on fuel economy rather than fuel consumption. This results in an ever-increasing overestimation of VMT response to increasing levels of CAFE, and an associated ever-increasing underestimation of fuel savings.
8) CAR neglects to reduce mass reduction costs estimated by the NAS to account for a NAS-identified 30 percent secondary mass reduction enabled by sufficient lead-time. CAR recognizes the secondary benefit in the text of their presentation, but their presented cost estimates are not adjusted to reflect the savings.
9) CAR incorrectly states that the 2010 NAS study "Assessment of Technologies for Improving Light Duty Vehicle Fuel Economy" (http://www.nap.edu/catalog.php?record_id=12924, hereafter referred to as the NAS Report) has a 15-year time horizon on costs and can, therefore, be used to estimate 2025 technology costs. The NAS study clearly constrains the applicability of its cost data to

the very near term (i.e., current implementation of the costed technology) as evidenced by such quotes as:

a. "Again, except where indicated otherwise, the cost estimates provided are based on *current conditions and do not attempt to estimate economic conditions and hence predict prices 5, 10, or 15 years into the future*." [NAS report page S-6, emphasis added]

10) CAR also relies on the NAS Report for its technology assumptions. As the NAS Report only assessed current technologies, CAR's technology assumptions also fail to address specific technologies that will play a critical role in attaining 2025 CAFE targets. Chief among these are cooled/boosted EGR -- which can extend the efficiency of SI (spark ignition) engine technology beyond levels associated with turbocharged, downsized, GDI technology -- and P2 hybrid vehicle technology -- which can deliver power split hybrid type efficiency impacts at considerably reduced cost.

11) CAR neglects to consider the potential for increases in fuel economy technology benefits relative to those estimated by NAS for current conditions -- despite the fact that the NAS Report explicitly acknowledged such potential.

Interpretive Issues:

a) In estimating CAFE-driven fuel savings benefits, CAR uses undocumented annual mileage rates that are significantly lower even than rates based upon nine-year-old 2001 FHWA NHTS data. Use of the most recent annual mileage rates from NHTSA imply savings a full 60 percent higher than those estimated by CAR.

b) CAR has misinterpreted the "universality" of the NAS 1.5 RPE (retail price equivalent) markup factor. NAS itself used a markup of 1.33 for their HEV cost estimates, properly recognizing that markup is dependent on exactly what costs are included in the "non-RPE" estimates. However, since CAR appears to take their baseline RPE data directly from NAS, their analysis inherently includes this caveat whether they realize it or not.

c) CAR assumes no learning for CAR-identified "mature" technologies, which has the effect of keeping their 2025 cost estimates for SI technology only marginally lower than their 2008 cost estimates for the same technology. Technology is only mature until a "better mousetrap" comes along, and for obvious reasons scientists and engineers are continually looking for a "better mousetrap." Take for example, automatic transmission technology, which CAR identifies as mature. No more than a few years ago, the design of the Lepelletier gear system produced substantial transmission technology cost savings. To assume that technology -- even mature technology -- will not continue to advance is, at best, shortsighted.

d) CAR assumes costs for mass reduction that do not change in accordance with the extended lead-time and associated ability for optimized system-wide redesign that it enables.

e) CAR incorrectly assumes a VMT elasticity that is much higher than available statistical data would support. When properly expressed in fuel consumption space, the CAR elasticity ranges from -0.152 to -0.219 for their three analysis scenarios. By comparison, available data would imply a 2025 elasticity of less than -0.03. This results in an overestimation of VMT response to increasing levels of CAFE, and an associated underestimation of fuel savings.

f) CAR applies a fuel savings discount to "current year" mileage, leading to an underestimate of fuel savings (a 9 percent underestimate given CAR's assumed discount rate) relative to an analysis that discounts savings only "future year" mileage.

To help illustrate the magnitude of the errors in CAR's analyses, the following Summary Table presents:
(1) The results from the CAR December 2010 presentation.
(2) The net vehicle price changes (increased vehicle price less first 5 years of fuel savings) that would be expected if CAR's calculations were corrected to reflect only the first seven factual errors listed, above:

- Proper expression of NAS impact estimates in fuel economy space.
- Proper aggregate fuel economy calculations in fuel consumption space.
- Inclusion of the air conditioning GHG credit
- Removal of safety equipment price impact estimates.
- Proper inclusion of in-use fuel economy adjustments.
- Proper accounting of PHEV and EV fuel economy impacts.
- Proper formulation of VMT elasticity in fuel consumption space.

(3) The net vehicle price changes if all of the errors were corrected and 2025 technology benefit and cost estimates from NHTSA/EPA were used instead of the current technology benefit and cost estimates from the 2010 NAS report.

Since the first seven corrections indicated above would also alleviate the need for PHEV and EV technology, we have also excluded the cost of electricity and associated recharging equipment from the net vehicle price change ($150, $558, and $1,212 for the 41.7, 49.8, and 60.1 mpg scenarios respectively) for the corrected values. We have not, however, adjusted the CAR-estimated technology market penetrations to remove the PHEV and EV technology vehicles from the fleet for the second set of values, which would, if performed, substantially reduce the CAR-estimated aggregate vehicle price increase from the levels indicated in the table. This, the second set of values should be viewed as a conservatively high estimate of vehicle price increases. The table also presents the results with and without the use of a more realistic annual VMT estimate.

It is important to recognize that the second set of values presented in this table do not include factual errors 8) through 11) or any of the interpretive issues, although the table includes alternative numbers with and without interpretive issue a)**.** These values do not include the additional revisions required to more appropriately reflect reality and do not reflect the estimates that the ICCT would derive for a similar cost benefit analysis. The tabulated values reflect only those revisions needed to correct only the most egregious errors in the CAR analysis.

The second set of values in the Summary Table show that the net impact of the first seven factual errors alone are sufficient to alter the fundamental economic conclusions contained in the CAR presentation. The confusion of fuel consumption and fuel economy impacts is sufficient in and of itself to induce a cascading series of fuel economy underestimates and technology cost overestimates throughout the larger analysis.

Summary Tables: Costs and Benefits Calculations

Scenario	RPE	5 Year Fuel Savings ($3.50/gal)		Payback (years)		Actual mpg	CAFE Achieved
		Without VMT Correction	With VMT Correction	Without VMT	With VMT		
CAR Analyses from December 2010 presentation – without any corrections							
41.7 mpg	$5,840	$1,690		20 +			
49.8 mpg	$7,281	$2,223		20 +			
60.1 mpg	$9,147	$2,693		20 +			
CAR Scenarios + two additional scenarios – with errors corrected and excluding the cost of safety equipment and electricity and recharging equipment – but still using 2010 NAS Report costs and benefits for 2025							
41.7 mpg	$4,190	$2,656	$4,248	9.6	4.9	47.6	51.8
49.8 mpg	$5,223	$3,071	$4,911	10.9	5.4	54.0	59.5
60.1 mpg	$6,435	$3,459	$5,532	12.8	6.2	61.9	69.3
100% SI (1)	$2,057	$1,850	$2,959	5.7	3.2	39.3	42.2
82% SI/18% HEV (2)	$3,070	$2,340	$3,742	7.2	3.9	44.0	47.6
EPA/NHTSA 2025 analyses in the Joint Technical Report for the 2017-25 Notice of Intent (best pathway)							
3% per year (3)	$1,070 (4)	$2,264	$3,620	2.1	1.2 (5)	43.2	46.7
4% per year (3)	$1,700 (4)	$2,615	$4,182	3.0	1.7 (5)	47.1	51.3
5% per year (3)	$2,400 (4)	$2,946	$4,710	3.9	2.2 (5)	51.4	56.3
6% per year (3)	$3,100 (4)	$3,247	$5,193	4.7	2.7 (5)	56.0	62.0

(1) CAR pathway SI-1. Scenario uses CAR elasticity estimate for the CAR 41.7 mpg scenario.
(2) CAR pathways SI-2 and E-1 (HEV). Scenario uses CAR elasticity estimate for the CAR 41.7 mpg scenario.
(3) Scenario uses CAR discount assumptions and elasticity estimate for the CAR 41.7 mpg scenario. The EPA/NHTSA data is recalculated using 2008 as the baseline year instead of 2016, so the RPE and the fuel savings are larger than those calculated by EPA/NHTSA in the NOI for 2016 to 2025.
(4) Includes $300 adjustment from 2016 to 2008 baseline.
(5) EPA-estimated payback periods relative to a 2016 baseline are 1.4, 1.9, 2.5, and 3.1 years for the 3%, 4%, 5%, and 6% scenarios respectively.

Note that the actual mpg achieved, in the second to last column, under each of the CAR scenarios is much higher than presented by CAR. The last column shows the CAFE level that would be achieved including the air conditioning credits, which is higher yet. For example, the actual stringency of CAR's 41.7-mpg scenario represents a CAFE level of 51.8 mpg. We have added two scenarios to illustrate what the RPE and fuel savings would have been for scenarios similar to the 41.7 mpg and 49.8 mpg goals, still using the inappropriate technology costs and benefits from the 2010 NAS Report.

Even without updating any of the technology or cost estimates from 2010, the payback periods are reasonable at $3.50 per gallon. The 100% SI scenario achieves 42.2 CAFE at a payback of less than 3 years even using the NAS Report 2010 cost and technology assumptions. Adding some additional SI improvements and a modest 18% hybrid market share almost achieves the 49.8 CAFÉ level with a payback of less than 4 years.

Finally, the third set of values in the Summary Table reflect the use of the EPA/NHTSA analyses for the 2017-25 Notice of Intent, as one example of the much lower costs and payback period when the numerous technology improvements and cost reductions expected over the next 15 years are included. The values show that the payback period is less than 2 years for 4% per year CAFE increases and less than 3 years for 6% per year CAFE increases if all of the corrections are included along with the use of representative 2025 technology costs and benefits.

Detailed Observations

The following comments are intended to provide elaboration on the summary issues described above. For convenience, the comments are formatted so that they can be related to specific elements of the CAR presentation on a page-by-page basis.

Slides 1-3 (Introductory slides)

No comment.

Slide 4 (heading: Why Higher FE Mandates?)

This is a non-substantive comment in that is has no effect on the CAR analysis, but it is interesting to note the inclusion of the qualifier "thought" in each bullet point on this slide. Certainly the first bullet point is well accepted, and the second is at most a matter of timing. While the last two points have elements of subjectivity, the tenor of the presentation is clearly established by the need to include this slide at all. Such a slide might be of interest if the issue is whether CAFE is warranted at all, but it has no bearing on what the proper level of CAFE should be if its existence is assumed -- cost effective CAFE is determined by the relationship between vehicle prices and fuel savings, regardless of one's opinion on climate science.

Slide 5 (heading: 2025)

Bullet point 1: "47 to 62 mpg mandates by 2025." This estimate of potential CAFE standards under the EPA's 2017-2025 Notice of Intent is wrong, as it fails to take into consideration the air conditioning credits that will be "added" to the EPA GHG standards before setting "equivalent" CAFE standards. Adjustment of CAFE standards to reflect GHG credits that do not otherwise affect measured vehicle CAFE has been included in every rulemaking associated with the adoption of GHG standards and the 2017-2025 rulemaking will certainly be no different. Our calculations place the correct range of CAFE at 43 to 56 mpg for a program that would have equivalent standards of 47 to 62 mpg in the absence of GHG credits.

Bullet point 2: "2010 NAS study … has 15 year horizon on costs and can be used with modifications to estimate technology costs." Unless the implied modifications are significant (which they are not), this is factually incorrect. By the NAS' own admission through quotes such as:

> "Again, except where indicated otherwise, the cost estimates provided are based on current conditions and *do not attempt to estimate economic conditions and hence predict prices 5, 10, or 15 years into the future*." [NAS report page S-6, emphasis added]

There are any number of similar quotes throughout the NAS report, but this one is as concise and explicit as any. The NAS did attempt to estimate HEV costs through 2025, but for reasons that are unclear (and undocumented), the estimates that appear in the NAS technology cost summary tables and calculations appear to be based on their 2009 HEV cost estimates (which can only make sense if all of the other cost estimates are similarly applicable to 2009).

Slides 6-8 (generic information and additional introductory slides)

No comments.

Slide 9 (heading: Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy --- Summary – Over 40 Technologies)

The text on this slide (i.e., fuel economy is cost, not technology constrained) would generally be accurate if it were not for technology impact errors associated with the CAR analysis. Unfortunately, such errors (as documented in detail under the comments for slide 15 below) do constrain architecture-specific technology impacts and unduly force more expensive technologies into the market. In effect, because CAR has grossly underestimated the fuel economy impacts of SI (spark ignition engine) technology, they force more expensive CI (compression ignition engine) and HEV technology into the market sooner than required, and this further cascades to artificially accelerate PHEV and EV technology introduction. Within this context, CAR has artificially constrained technology relative to that which would be used to meet CAFE standards without such constraint.

The chart on this slide is misleading due to the way in which the NAS study committee presents their cost estimates -- estimates that we presume are the basis for the chart in the absence of alternative supporting documentation. The NAS estimates are all incrementally based, but *not against a common baseline*. Estimates for most technologies are premised on a NAS-selected order of implementation, which has the effect of reducing the effectiveness of a "later" technology relative to the impact it would have had if it were implemented earlier in the technology chain. There is nothing wrong with such an approach as long as its effects are recognized and accounted for, *as is not the case in a chart such as the one on this slide*. To properly show the impacts of differing technologies on an equal footing, the incremental nature of the NAS estimates would have to be removed and each technology evaluated in terms of its independent impact against a common baseline. As successive technologies are selected for implementation, the chart has to be reconfigured to each successive "new" baseline. This may be useful in an analysis to construct the most cost effective technology package, but is of little use in a presentation such as this -- especially in the absence of a proper explanatory foundation and caveats.

No effort was made to validate the values in the chart, even assuming the approach to its construction was correct. The bottom line is that the chart has no direct impact on the CAR forecasted futures.

Slide 10 (heading: Incremental Cost Estimates)

Bullet point 2: "an *average* RPE markup factor is 1.5 to get consumer price." [emphasis in original]. Much study has been devoted to the issue of what constitutes an appropriate RPE markup factor and there is no "definitive" right number. NAS uses 1.5 for SI/CI technology, but they reduce that factor to 1.33 for HEV technology, as they clearly state in their own words:

> "The committee's justification for using a RPE of 1.33 for hybrids is that the factory cost estimates it developed already includes engineering costs and other part costs, including labor and overhead, for integrating the technology. Using a cost multiplier of 1.5 would double count these costs." [sic, NAS report page 6-16]

EPA takes a different approach, one that varies the RPE factor with technology complexity and development time -- with RPE factors ranging from about 1.13 (long term, low complexity) to 1.7 (near term, high complexity). For the basket of technologies EPA expects on a 2025 SI/CI technology path, an average RPE factor would be about 1.25. Thus, CAR/NAS RPEs will be on average about 20 percent higher than EPA RPEs for SI/CI tech packages.[1] For HEVs, a typical EPA package would have a markup of about 1.51, higher than the NAS markup for HEVs. But there are far more significant HEV costing issues associated with the NAS estimates used by CAR. These issues are discussed in detail in the section for slide 15 below.

Bullet point 4: Cost reductions over time. These are essentially cost reductions that NAS applied only to HEVs and then chose to ignore in their final HEV costing. CAR is apparently adopting this same approach, but expanding it to *marginally* affect SI/CI technology in a fashion that NAS did not. NAS has plenty of statements in their report indicating the temporal limitations of their cost estimates, and it is not appropriate to infer otherwise (which is what the cited cost reduction approach does when it states that cost reductions are applied only to "advanced technologies" in accordance with a learning curve that NAS developed explicitly for HEV technology). See for example, the explicit statement included above under the comments for slide 5. Moreover, NAS acknowledges the potential for SI/CI (and other technology) cost reductions explicitly in statements such as:

> "The use of learning curves poses a dilemma. On the one hand, there is no rigorous method for determining how much and how rapidly a specific technology's costs can be reduced by learning-by-doing. On the other hand, the phenomenon of learning-by-doing is widely and generally observed in the manufacturing of new technologies (e.g., Wene, 2000). This does not mean that no learning should be assumed. Rather, learning curves should be applied cautiously and should reflect average rates of learning based on empirical evidence from the motor vehicle industry. Expert judgment should be used to determine the potential for learning, depending on the nature of the technology in question". [NAS report page 3-7]

NAS was simply not affected by the issue of cost reductions over time due to their self-imposed constraint of estimating only current costs. Thus, to assume that costs will not decline between now and 2025 for all but a CAR-selected subset of technologies is simply not supported by the plain language of the NAS report. Yet, CAR makes just such an assumption.

Although CAR appears to expand the NAS learning curves to cover SI technology, they assume no learning for CAR-identified "mature" technologies. This has the effect of keeping their 2025 cost estimates for SI technology only marginally lower than their 2008 cost estimates for the same technology. Technology is only mature until a "better mousetrap" comes along, and for obvious reasons scientists and engineers are continually looking for a "better mousetrap." Until a few years ago, automatic transmission technology was "mature" with state-of-the-art four speed designs. However, the development of the Lepelletier gear system produced substantial transmission technology cost savings and this "mature" technology advanced. To assume that technology -- even mature technology -- will not continue to advance is, at best, shortsighted.

[1] It is perhaps worth noting that EPA generally describes their factor as an ICM (indirect cost multiplier). In previous rulemakings, the EPA has excluded profit margin from their ICM and, therefore, EPA factors would generally not be directly comparable with RPE factors. However, for the 2017-2025 Notice of Intent markups cited here, the EPA has included the "missing" profit factor, so the markups are generally comparable.

Slide 11 (heading: Mass Reduction, in General, is not Free)

Third statement: "“Re-optimize” vehicle: 30% additional benefit in secondary mass reductions.” This again is a statement right out of the NAS report, but which is used to infer that such a benefit is reflected in the NAS numbers when it is actually not (nor is it considered in the chart presented on this slide by CAR). In discussing this optimization, the NAS report reads as follows:

> “An important consideration with mass reduction is that its effects on fuel consumption can cascade. As the mass of a vehicle is reduced in, say, the body or interior, other components of the vehicle can be reduced in size as a consequence. For example, brakes, fuel system, power train, and even crash-management structures can all be downsized for a lighter vehicle. In the study conducted by Ricardo (2007 for the Aluminum Association, the rule-of-thumb generated was that for every pound eliminated in the vehicle structure, an additional 0.30 pounds (30 percent) of mass could be reduced in other areas of the vehicle. If this rule-of-thumb is applied and mass reduction comes at a cost of $1.65/lb, then at an additional 30 percent of secondary mass savings (0.3 lb) the net cost per pound becomes $1.65/1.3 lb, which becomes $1.27/lb. It is important to note that achieving secondary savings typically requires reengineering one or more systems on the vehicle, and this would likely be performed according to the product development timing plan (see above the section “Timing Considerations for Introducing New Technologies”). So, achieving the 30 percent secondary benefit is in the long-term and not necessarily when the initial reduction in mass is achieved.” [sic, NAS page 7-25 to 7-26]

Thus, NAS recognizes the potential for longer term cost savings, but their estimates are based on “current” costs and do not take the savings into account, even though CAR tries to imply that they do. This correction alone would reduce the cost of mass reduction technology as shown in the chart on this page of the CAR presentation by 23 percent.

With regard to the cost of mass reduction in general (as depicted in the chart in the CAR presentation that compares NAS and NHTSA RPE estimates for reductions up to 20 percent, it is important to note that, as already described, NAS estimates reflect the current costs of replacing materials and augmenting production procedures in a grossly sub-optimum manner, with no consideration of lead time or streamlining overall design integration. Given sufficient lead time (as will be available for 2025 CAFE standards that are adopted in the next few years), advanced computer simulation and computer-aided-design will allow for optimization and dramatically reduce the cost of integrating new materials. While there remains much work to be done on this topic, it is clear from studies performed not by regulators, but by automotive development firms themselves, that incremental piece costs for reductions up to 20 percent *can be negative*. While changes in production and manufacturing costs may result in an overall increase in costs, that increase will not accrue in a near-term inefficient piece-by-piece substitution effort as inherently assumed in the NAS cost impact estimates, but instead though an efficient system-wide approach to total material and manufacturing redesign. To assume that the overall costs of these two approaches will be similar is simply not warranted.

Slide 12 (heading: Revolution in Batteries)

There would be absolutely no reason to bring this slide into the debate from a technical standpoint if CAR were to fix their cost and benefit estimates to undo “factual” errors (see the discussion for slide 15 below for the most egregious of these errors). Neither PHEV nor EV technology is required to meet the 2025 CAFE options that are included in the 2017-2025 Notice of Intent. Yes, manufacturers can obtain significant CAFE and GHG credits (and experience) by introducing both PHEV and EV technology prior to 2025, but there is nothing in the 2017-2025 CAFE options that would require such introduction. These technologies are not on the critical path for 2025 and thus have no impact on the cost of CAFE through that period. In this regard, it is simply a distraction to debate potential battery progress. Certainly, reductions in battery cost are expected to reduce "onboard-only" HEV costs, but this effect is substantially less significant on an overall cost basis than is the case for PHEV and EV technologies with their substantially larger energy and power demands.

It is also perhaps worth noting that the charted data presented on this slide (and attributed to NAS) do not come from the NAS report that serves as the primary reference for the CAR presentation. The apparent reason for this is that the primary NAS reference includes no battery cost estimates for PHEV and EV technology. The presented data appear to be derived from a 2010 NAS report on plug-in hybrid vehicles,[2] but it is not clear as the presented data do not appear to precisely match the data from that reference either. As shown in Figure 1, the cost estimates that CAR attributes to NAS are higher than even the most conservative cost assumptions from the NAS plug-in report. And this is in comparison to NAS PHEV report estimated future battery costs that are already quite conservative, based on the stated premise that:

> "Lithium-ion battery manufacturing is a well-developed technology. Worldwide over a billion Li-ion cells are currently produced every year." [NAS plug-in HEV report page 11]

Such a premise inherently assumes that vehicular battery applications are comparable to those of electronic devices that generate the current Li-ion demand, and this is simply not the case. Table 6-1 and associated discussion in the primary NAS report show quite clearly the aggressive efforts that are ongoing with regard to vehicular applications to both improve current Li-ion technology and develop alternative Li-ion chemistries. This is by no means a static and mature technology with regard to automotive applications. The primary NAS report included Finding 6-3, a determination that:

> "During the past decade, significant advances have been made in Li-ion battery technology. When the cost and safety issues associated with Li-ion batteries are resolved, they will replace NiMH batteries in HEVs and PHEVs. A number of different Li-ion chemistries are being studied, and it is not yet clear which ones will prove most beneficial." [NAS report page 6-22]

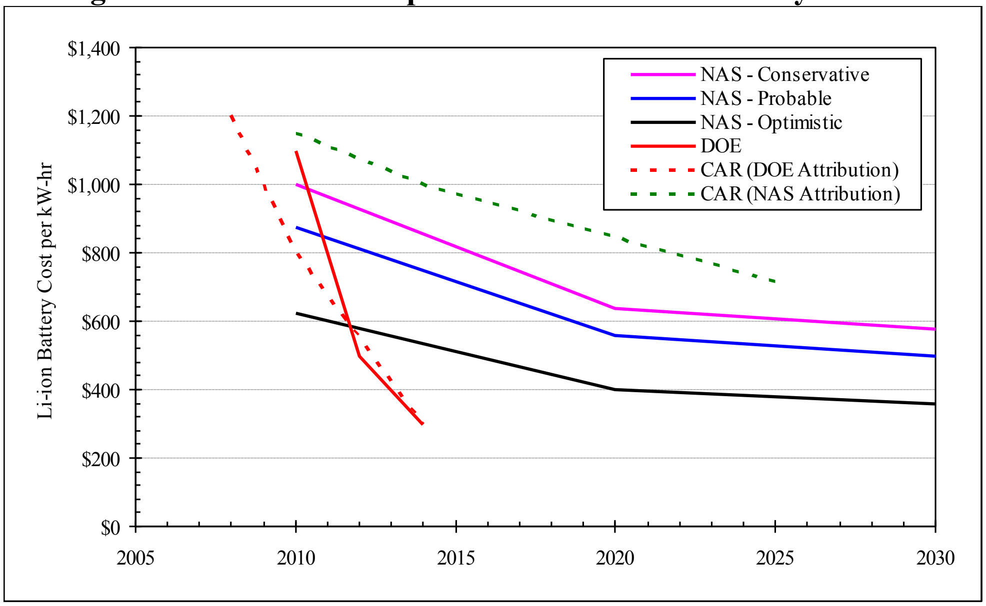
Even the NAS plug-in HEV report acknowledges this by concluding:

> "Future battery and battery-pack costs are quite uncertain at this point. For that reason the committee feels that it will be important to reevaluate these costs in several years, when significant data on the first production cycle of PHEVs is available, which should allow better projections." [NAS plug-in HEV report page 11]

To claim that NAS sees no potential for significant battery cost reductions is simply unfounded. In fact, as shown in Figure 1, by 2025 the optimistic case cost assumptions of the NAS plug-in HEV report are quite similar to those of the DOE -- they just accrue over a longer timeline. It is clear that battery progress is continuing and while it is not possible to forecast future costs with certainty, it is misleading to characterize this area of research as likely to be unfruitful over the next 15 years.

[2] National Academy of Sciences, National Research Council, "*Transitions To Alternative Transportation Technologies—Plug-In Hybrid Electric Vehicles*," National Academy Press, Washington, D.C., 2010.

Figure 1. NAS PHEV Report and DOE PHEV Battery Cost Estimates



Slide 13 (heading: none, discusses battery technology)

Due to the lack of a need for either PHEV or EV technology to meet the 2025 CAFE options that are included in the 2017-2025 Notice of Intent, this slide, like slide 12, is unnecessary. Nevertheless, it is important to note that battery technology advances are not limited to PHEV and EV applications. High-power Li-ion batteries are now entering the "onboard recharge" HEV market. These batteries will be able to provide greater power assist functionality as well as capture larger amounts of regenerative braking energy relative to the NiMH batteries they displace -- while simultaneously cutting battery pack size and cost by a factor of two. Battery research is not static and advances are not 15 years or more removed.

Slide 14 (heading: Three Principal Pathways)

This slide lays out three alternative technology pathways (which mimic pathways presented in the NAS report). As the CAR analysis is based upon the fuel economy impact and costs of these pathways, certain constraining issues should be recognized.

<u>SI Pathway</u>: The CAR/NAS SI pathway does properly reflect the "workhorse" turbocharged, downsized, GDI technology that is expected to be in widespread use in response to required CAFE increases. The package does, however, omit technology such as cooled/boosted EGR that will be available between now and 2025. This technology alone will close a substantial fraction of the efficiency differential that remains between SI and CI after the introduction of turbocharged GDI. It also allows for reduced or eliminated power enrichment and should effectively alleviate the need for more expensive CI technology.

CI Pathway: CI technology is fine to discuss and evaluate, but it is generally not cost effective when compared to SI and HEV technology. Outside of European manufacturers and suppliers, no one is predicting large increases in CI market penetration, at least not without large increases in U.S. fuel prices. Once the factual errors related to the CAR fuel economy benefit assumptions are corrected (as described in detail in the section on slide 15 below), any need for CI technology for CAFE compliance purposes is alleviated.

HEV Pathway: There are both cost and technology issues associated with the CAR/NAS HEV pathway. The cost issues are discussed in detail in the section that follows on slide 15, so only the technology issues are discussed here. First, despite the fact that it is listed in their report schematic, NAS does not include PHEV technology in their HEV pathway. As is clearly denoted on the pathway schematic, PHEV technology is not included in the aggregate impact estimates for the pathway. So, while this slide makes it appear that the NAS HEV pathway includes PHEV technology, that is not actually the case. More importantly, NAS HEV estimates are based on Toyota power split technology, and this is not expected to be the dominant technology for HEVs, even in the relative near term. Most HEVs entering the market in the next year rely on so-called “P2” technology that offers 90% to 95% of the benefits of the power split, but at substantially lower cost. This is a major omission of the NAS report that CAR makes no effort to address. P2 HEVs save costs by better integrating hybrid and conventional technology. They rely on a conventional transmission and a *single* electric machine rather than the complex power split device and *dual* electric motors, both of which are larger than the single motor in the P2, used in the Toyota power split system. This obviously saves parts costs, but the savings go even further in that the P2 technology is designed to minimize packaging, maintenance, and warranty issues and can maintain its efficiency benefits with a smaller battery pack. Since the P2 technology is entirely missing from their HEV pathway, neither NAS nor CAR reflect such benefits in their cost estimates.

Slide 15 (heading: Technology Cost Summary)

This slide provides the basic fuel economy benefit and cost estimates upon which CAR’s entire analysis is premised. Unfortunately, they have made several major errors, both factual and interpretive. The most egregious of these is the fact that CAR presented NAS fuel *consumption reduction* impacts as fuel *economy increase* impacts. Because they are presented as percentages versus the same denominator, decreases are always a smaller percentage than comparable increases. The net result is that CAR’s fuel economy estimates are off by a significant margin simply due to this computational error. Table 1 illustrates the magnitude of this error. For example, CAR treats the SI-3 technology pathway as though NAS reported a 38% increase in fuel economy. However, NAS reported a 38% decrease in fuel consumption, which is equivalent to a fuel economy increase of 61 percent (1/(1-38%)), far larger than the increase of 38 percent reported by CAR. Clearly this has implications that ripple throughout the entire CAR analysis and it should be emphasized that this is not a matter of opinion or interpretation, but a matter of simple mathematics. The CAR analysis is simply wrong.

Table 1. CAR Fuel Economy Impacts

Pathway	CAR FE Change (a)	Adjusted FE Change (b)
SI-1	30%	43%
SI-2	36%	56%
SI-3	38%	61%
CI-1	38%	61%
CI-2	40%	67%
E-1 (HEV)	44%	79%
E-2 (HEV)	47%	89%
E-3 (PHEV)		
E-4 (EV)		

(a) CAR labels and treats these values as fuel economy (FE) increases, when they are actually fuel consumption reductions.

(b) These are the correct fuel economy impacts for the fuel consumption reduction impacts in the previous column.

This factual correction *alone* is critically important compared to the percentage change in CAFE that could be required for targets of 43-56 mpg in 2025 relative to a baseline CAFE of about 27.5 mpg. These targets would require fleet average CAFE increases of 56-104 percent -- increases that (on the low end) are clearly achievable with even CAR's SI package benefits and nearly achievable (on the high end) with even CAR's HEV package benefits.

CAR's data for the E-3 and E-4 paths have been omitted from Table 1, as they are derived independent of the NAS report and appear to be fuel economy based. On slide 24 of their presentation, CAR provides a statement that the E-3 (PHEV) impact is based on data from Toyota for a PHEV with a 15 to 20 mile electric range, but no supporting data is presented. However, CAR's estimated 144 percent (regulatory) fuel economy increase appears to be rather low, given current CAFE procedures. While test procedures for PHEVs are subject to potential future revision, there are existing provisions in CAFE rules that effectively treat PHEVs as dual fueled vehicles -- providing EV-type credit multipliers for EV mode operation and equally weighting measured non-EV and EV mode fuel consumption estimates to derive an overall CAFE fuel economy estimate. Implementing such a procedure using EV mode consumption data for current EVs and the Chevrolet Volt demonstrates that a more realistic CAFE multiplier for PHEVs is around 3.5 (i.e., a 250 percent regulatory fuel economy increase). Of course, this could change if NHTSA ultimately adjusts their CAFE procedure to alter the current equal operating mode weighting, but EV-mode shares for both PHEV20s and PHEV40s are estimated to be relatively near 50 percent (below and above respectively), so the net effect of any correction is likely to be minor (relative to a corrected "default" 3.5 multiplier).

For pathway E-4 (EV), CAR indicates on slide 25 that they essentially "split the difference" between an "EPA guidance" multiplier of 2-3 and a CAFE multiplier of 10. However, both of these estimates are wrong with regard to the analysis being conducted by CAR. When the specific requirements for incorporating EVs into the GHG and CAFE standards are considered, as explained in detail in the discussion of slide 25, below, the most appropriate fuel economy impact (expressed as percentage change in fuel economy) for EVs is not 600 percent as assumed by CAR, but 1,100 percent as dictated by current NHTSA CAFE rules.

The corrected fuel economy impacts for CAR technology pathways E-3 and E-4 are summarized in Table 1a.

Table 1a. CAR Fuel Economy Impacts

Pathway	CAR FE Change	Adjusted FE Change
E-3 (PHEV)	144%	250%
E-4 (EV)	600%	1100%

An even larger impact is CAR's use of the NAS report average data. The NAS estimates both fuel consumption and cost impacts as ranges, and then uses a simple arithmetic average of each for its "best" estimates. However, as previously discussed, the NAS report restricted their cost and benefit analysis to reflect "current" conditions representative of 2010, not 2025. Further, the NAS recognized that their estimates over time may skew away from current averages. For example, as they themselves state:

> "Note that the ranges associated with these technologies do not reflect the possibility that, *over time, the average fuel consumption benefit could tend toward the high end of the range as the lessons learned from the best examples of the technology spread across the industry and as the impacts of higher CAFE standards increase*." [NAS report page 9-6, emphasis added]

> "However, as evidenced by the increasingly wide range in estimated fuel consumption reduction and incremental cost, actual fuel consumption improvement can vary significantly depending upon individual manufacturer's product strategy. Further, *it may be that the needs to reduce vehicle fuel consumption as mandated by recent legislation will result in OEMs implementing these technologies in such a way that the benefits fall towards the high end of the range*." [NAS report page 9-18, emphasis added]

Virtually any fuel efficiency technology can be implemented to benefit either performance or fuel economy (or both) and NAS rightly points out that through both learning and CAFE-influenced decision-making, future fuel efficiency implementations will shift in such a way as to promote fuel economy impacts at the high end of the NAS ranges.

NAS also rightly points out that appropriate timing (allowing manufacturers to integrate new fuel efficiency technology into their vehicle redesign schedule) will enhance the ability of vehicle manufacturers to maximize fuel economy benefits.

> "The timing for introducing new fuel consumption technologies can significantly influence cost and risk. [NAS report page 7-17]

The NAS report goes on to show how non-power train technologies that could have less than a 3 percent fuel consumption impact if implemented quickly without proper recognition of manufacturer redesign schedules, can reduce fuel consumption by as much as 13-18 percent if implemented as an integral component of the redesign schedule (see specifically NAS report, Table 7-6, page 7-27). Since one of the main rationales behind the 2017-2025 GHG/CAFE proposal is to allow manufacturers sufficient lead time to achieve just such integration, it is clearly reasonable for manufacturers to be able to deliver fuel efficiency benefits above the current fuel economy average. One way for a 2025 analysis to account for this is to look at the impacts that the NAS report would predict if such high range benefits did accrue.

Table 2 presents the corrected CAR fuel economy impact estimates augmented to include the upper bound range of NAS impact estimates. The values in parenthesis reflect the uncertainty estimates produced by the NAS. The NAS estimates apply explicitly to pathways SI-1 and E-1. They were extended to the other tabulated pathways (developed by CAR) using relations proportionally to the CAR "baseline" relationships. The net impacts of this exercise are shown in Table 2. The required fleet average CAFE increases of 56-104 percent are now well within the range of achievable fuel economy using SI and HEV technology alone.

Table 2. NAS High End Fuel Economy Impact Estimates

Pathway	CAR FE Change	Adjusted FE Change	NAS High FE Change
SI-1	30%	43%	56% (50-62%)
SI-2	36%	56%	73% (65-81%)
SI-3	38%	61%	79% (71-89%)
CI-1	38%	61%	
CI-2	40%	67%	
E-1 (HEV)	44%	79%	130% (80-219%)
E-2	47%	89%	147% (91-247%)
E-3 (PHEV)	144%	250%	
E-4 (EV)	600%	1100%	

A more direct source of 2025 benefit and cost information is contained in the documentation associated with the EPA's 2017-2025 Technical Analysis Report (TAR).[3] It is not possible to find an EPA technology package that exactly matches that assumed by the NAS, but large car package 504 in the TAR appears to be reasonably close (the NAS estimates used by CAR are applicable to the intermediate, large car, and unibody standard truck classes). The EPA and NAS base engines and transmissions are the same (DOHC V6, A4). Package 504 includes greater mass reduction at 15 percent (which is "worth" an approximate additional 6 percent fuel consumption reduction relative to NAS' assumed 5 percent mass reduction), but the NAS package includes CVVL (which is worth an approximate additional 2.5 percent relative to package 504's DVVL), a 10 percent aerodynamic drag reduction (which is worth an approximate additional 1.5 percent relative to package 504), electric power steering (which is worth an approximate additional 2.0 percent relative to package 504), and improved accessories (which are worth an approximate additional 1 percent relative to package 504). So, there is a net unmatched benefit of about 6 percent on the EPA side as compared to a net unmatched benefit of about 7 percent on the NAS side, making them roughly equivalent. Package 504, as estimated via the EPA's OMEGA model, has a net fuel consumption reduction of 36.6 percent, or a net

[3] U.S. Environmental Protection Agency, U.S. Department of Transportation, National Highway Traffic Safety Administration, and California Air Resources Board, "*Interim Joint Technical Assessment Report: Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2017-2025*," September 2010

fuel economy increase of 58 percent -- which compares quite favorably with the NAS high fuel economy impact estimate of 56 (±6) percent as tabulated for pathway SI-1.

EPA package 517, which is a P2 HEV package for the large car class, has a modeled fuel consumption reduction of 47.4 percent, or a net fuel economy increase of 90 percent -- which also compares reasonably well with the NAS high fuel economy impact estimate of 80-219 percent, as tabulated for pathway E-1.[4] However, it should be recognized that EPA's treatment of HEVs is somewhat different than that of the NAS. Whereas NAS treats the HEV as a package that is independent of changes to ICE engines such as turbocharging and GDI, EPA treats HEV technology as an incremental improvement to underlying ICE technology. Thus, the EPA also has, for example, HEV package 525 that is similar in all respects to package 517 except that it includes turbocharged GDI with cooled/boosted EGR. Package 525 has a modeled fuel consumption benefit of 55.1 percent, or a net fuel economy increase of 123 percent -- which is more in line with the 130 percent midpoint estimate of the NAS high fuel economy impact estimate for pathway E-1.

Thus, the high impact NAS estimates appear to be quite consistent with the EPA impact estimates.

For costs, quotes above in the sections for slides 5, 10, and 11 provide a strong rationale for also looking at the low end of the NAS current cost range for at least an indication of potential 2025 system costs. This is, in no way, meant to restrict a true 2025 cost analysis to the low end of the NAS cost impact range since they themselves made no effort to estimate 2025 costs. Simply that such a look could provide a glimpse of costs that NAS considers possible, *even today*.

Table 3 presents a comparison of CAR cost impacts with costs from the low end of the NAS estimated cost range. The NAS RPE estimates are split into two sections. In the next to last column, NAS HEV RPE estimates reflect an adjustment of their 2009 HEV costs to reflect 2025 costs based on cost ratios presented in Table 6-4 of the NAS report (NAS report page 6-18). The SI costs are 2009 costs, as NAS provides no future cost estimates for SI vehicles. In the rightmost column, NAS HEV RPE estimates for 2025 are presented, but substituting an ISG/IMA HEV system for the default power split HEV assumed by NAS. It is not clear why NAS chose to utilize the power split architecture, as it is far less cost effective (by their estimates) than ISG/IMA technology. The NAS 2009 cost estimate for the ISG/IMA system is $1,400 cheaper (nearly $1,900 RPE), but NAS estimated the ISG/IMA would provide over 95 percent of the power split fuel economy benefit (on average). The only justification (based on NAS data) for selecting the power split over the ISG/IMA is to achieve maximum fuel economy benefits regardless of cost, but it is also interesting to note that the two systems do diverge in terms of their NAS-estimated high end efficiency potential -- so that NAS possibly had this in mind when selecting power split technology over ISG/IMA technology. Of course, regardless of the NAS rationale, none of this corrects for the "missing" P2 HEV technology cost estimates that would deliver power split type benefits at substantially reduced cost.

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[4] It is important to recognize that small changes in fuel consumption in this range of benefits equate to large changes in fuel economy. The entire 80-219 percent fuel economy increase range corresponds to a fuel consumption reduction range of 44-69 percent.

Table 3. NAS Low End Fuel Economy Technology Costs

Pathway	CAR 2008 RPE	CAR 2025 RPE	NAS Low Cost RPE (2025 HEV)	NAS Low Cost RPE (2025 ISG/IMA HEV)
SI-1	$2,200	$2,057	$1,373 ($1,108-$1,637)	$1,373 ($1,108-$1,637)
SI-2	$3,060	$2,861	$1,909 ($1,541-$2.227)	$1,909 ($1,541-$2.227)
SI-3	$3,945	$3,688	$2,461 ($1,987-$2,936)	$2,461 ($1,987-$2,936)
CI-1	$5,900	$5,517		
CI-2	$6,760	$6,320		
E-1 (HEV)	$6,000	$4,020	$3,488 ($2,887-$4,089)	$3,184 ($2,635-$3,733)
E-2	$6,860	$4,596	$3,988 ($3,300-$4,675)	$3,640 ($3,013-$4,268)
E-3 (PHEV)	$11,000	$8,710		
E-4 (EV)	$22,000	$14,740		

Using the same EPA tech packages cited above for the fuel economy benefit comparison, comparative SI and HEV system costs are available. For the SI-1 pathway, EPA estimates a 2025 RPE-equivalent price increment of $697 for tech package 504. Applying a 20 percent premium to this price to convert to an approximate 1.5 RPE markup, as used by NAS, yields an NAS-comparable RPE of $837 -- below the 2009 NAS low end costs ($1,108-$1,637), but not at all unreasonable given that NAS made no effort to forecast SI cost reductions through 2025. Both the EPA and NAS low cost RPEs are significantly lower than the $2,057 RPE assumed by CAR.

The EPA HEV tech packages 517 and 525, both based on P2 HEV technology, have estimated RPE-equivalent price increments of $2,857 and $3,928 respectively. These compare quite well with the NAS-forecasted low cost HEV RPEs for 2025 -- with both EPA and 2025 NAS low cost RPEs substantially lower than the 2025 HEV costs assumed by CAR.

Finally, it is important to note that NAS explicitly recognized the importance of teardown cost estimation -- the primary costing methodology being employed by EPA in their estimation of potential 2017-2025 compliance costs. In NAS' own words:

> "There is a need for cost estimates based on a teardown of all the elements of a technology and a detailed costing of material costs, accounting for labor time and capital costs for all fabrication and assembly processes. Such studies are more costly than the current approaches listed above and are not feasible for advanced technologies whose designs are not yet finalized and/or whose system integration impacts are not yet fully understood. Nonetheless, estimates based on the more rigorous method of teardown analysis are needed to increase confidence in the accuracy of the costs of reducing fuel consumption." [NAS report page 3-23]
>
> "Cost estimation using the teardown approach is discussed in Chapter 3. *The committee finds this approach an improvement over one where cost estimates are developed through expert knowledge and surveys of suppliers and OEMs, which have been the basis for most published studies and the majority of this report.* Furthermore, the committee recommends that the use of teardown studies be expanded for future assessments when cost-effectiveness is an important evaluation criterion." [NAS report page 9-8, emphasis added]

Clearly, NAS recognizes the superiority of the EPA teardown cost estimation approach and, as a result, EPA costs based on teardown studies should be given full and thoughtful consideration, especially when associated estimates diverge from those developed by NAS using less robust methodologies. Instead, CAR choose to rely on NAS estimated current costs without further consideration.

Slide 16 (heading: Incremental Technology Price & Effectiveness)

The key points related to the impropriety of the presented data were summarized, above, in the section on slide 15, Figures 2 and 3 simply recreate CAR's chart using only the corrections to the CAR data and the other relevant data from the slide 15 discussion above (i.e. the other corrections discussed above are not included in Figures 2 and 3). Two versions of the chart are shown. Figure 2 is presented solely to emphasize the visual distortion created by CAR's use of a skewed x-axis. Figure 3 (the same chart but with restricted axes) is provided to show the "important" range of the data on a continuous x-axis scale. The reduced costs and extended fuel economy impact range of the corrected SI and HEV data are obvious. Simply correcting the use of fuel consumption reductions as fuel economy increases drops the cost of complying with a given level of fuel consumption by more than 25%. Also using benefit and cost data representative of 2025, instead of current benefits and costs, drops the cost of complying by well over 50%.

Figure 2. Summary of Costs and Benefits, Extended Scale

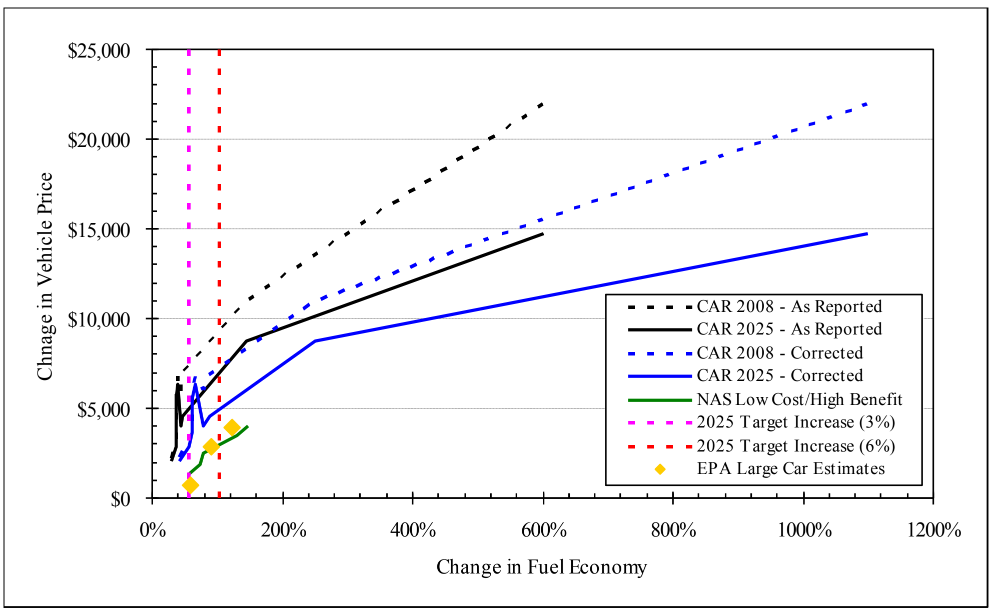
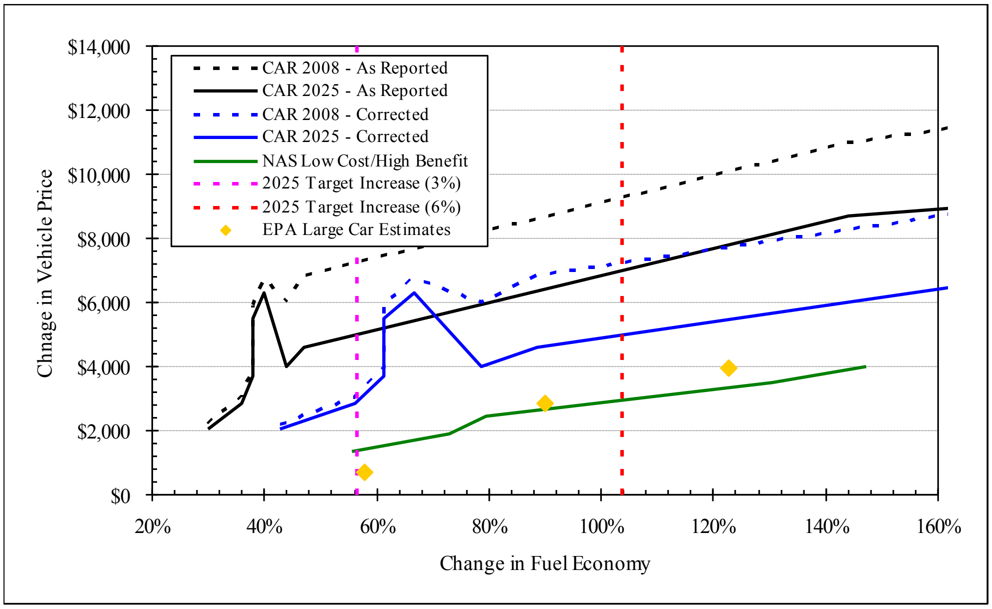


Figure 3. Summary of Costs and Benefits, Restricted Scale



Slide 17 (Another intro slide)

No comments.

Slides 18-21 (heading: CAFE Scenario Assumptions)

This slide lays the foundation for three alternative CAFE scenarios presumably developed by CAR. The three include 41.7 mpg as a "low CAFE target," 49.8 mpg as a "medium target," and 60.1 mpg as a "high mileage scenario." It is important to understand how these scenarios relate to the specific proposals in the 2017-2025 Notice of Intent, as CAR neglects to consider the air conditioning credit adjustment required to create equal stringency GHG and CAFE standards. The 2017-2025 Notice of Intent options and CAR scenarios breakdown as follows:

Annual GHG Reduction from 2016	Equivalent 2025 Fuel Economy Without Credit Adjustment	Equivalent 2025 CAFE With Credit Adjustment
3%	46.7 mpg	43.2 mpg
4%	51.3 mpg	47.1 mpg
5%	56.3 mpg	51.4 mpg
6%	62.0 mpg	56.0 mpg
2.58%	44.9 mpg	**41.7 mpg**
4.64%	54.5 mpg	**49.8 mpg**
6.82%	67.1 mpg	**60.1 mpg**

Note that the CAR options are treated as CAFE standards, since that is how CAR treats them in their costing analysis. As indicated, the "high mileage" standard that CAR claims is equivalent to the 6 percent 2017-2025 Notice of Intent option is actually closer to a 7 percent option and thus exaggerates the costs of the most aggressive 2017-2025 Notice of Intent option *for any given set of cost assumptions*. The "medium target" CAR option is much closer to the 5 percent 2017-2025 Notice of Intent options than the midpoint of the 3 and 5 percent options, as claimed by CAR. The "low CAFE target" option is less aggressive than even the most lenient 2017-2025 Notice of Intent option.

Slides 22-24 (heading: CAFE Scenario Caveats)

<u>Bullet point 3: "fuel economy multiplier for plug-in hybrid electric vehicles."</u>
The fuel economy multiplier that CAR uses for plug-in HEVs is significantly too low. CAR indicates that their estimated impact is based on data from Toyota for a PHEV with a 15 to 20 mile electric range, but presents no data. While test procedures for PHEVs are subject to potential future revision, there are existing provisions in CAFE rules that effectively treat PHEVs as dual fueled vehicles -- providing EV-type credit multipliers for EV mode operation and equally weighting measured non-EV and EV mode fuel consumption estimates to derive an overall CAFE fuel economy estimate. Implementing such a procedure using EV mode consumption data for current EVs and the Chevrolet Volt demonstrates that a more realistic CAFE multiplier for PHEVs is around 3.5 (i.e., a 250 percent regulatory fuel economy increase), as compared to the 2.44 multiplier used by CAR. This PHEV fuel economy impact underestimation leads directly to an overestimation of the number and cost of PHEVs in any scenario for which CAR assumes a need for such technology. If the other errors in CAR's analyses are corrected, there is no scenario in the 2017-2025 Notice of Intent that would require the marketing of PHEVs (at least through 2025), so there is no real effect of changing the multiplier. However, this is not the case for the presented CAR estimates, where they assume a PHEV market share as high as 24 percent.

Slide 25 (heading: CAFE Scenario Caveats, Electric Vehicles)

CAR indicates that they essentially "split the difference" between an "EPA guidance" multiplier of 2-3 and a CAFE multiplier of 10 to estimate the CAFE fuel economy of EV technology. However, both of these estimates are wrong with regard to the analysis being conducted by CAR. The CAFE multiplier is based on a cited Tesla Roadster CAFE value of 244 mpg, which would indeed imply a multiplier of about 10. However, that CAFE figure was, for reasons unknown, actually developed internally by Tesla, which obviously did not understand how NHTSA evaluated EV CAFE. The EPA-tested figure for the Tesla for model year 2010 is 346.8 mpg. Using consumption data for the Nissan Leaf, CAFE fuel economy can be similarly estimated at about 344 mpg. Both values are easily derived using existing NHTSA CAFE procedures for EVs and certification fuel consumption of 0.23-0.24 kW-hrs per mile (varying by vehicle). The Chevrolet Volt has slightly higher EV-mode fuel consumption, so that if it were an EV, it would have a CAFE value of about 326 mpg. Based on these data, EVs are more appropriately modeled using a CAFE multiplier of about 12.

Of course, the CAFE multiplier does not apply to EPA GHG standards and it is therefore appropriate to consider potential GHG rule implications. While CAR cites an "EPA guidance" multiplier of 2-3, existing EPA GHG standards treat EVs as having zero CO_2 emissions and the agency treated EVs similarly in their impact analysis of potential 2017-2025 GHG standards.

> "In the assessment of potential future ranges of stringency presented in this report, we based our compliance analysis on the tailpipe emissions from all vehicles – thus EVs were evaluated at a 0 gram/mile CO_2 level and PHEVs were evaluated as 0 gram/mile for the electric drive portion of the vehicles operation." [EPA 2017-2025 Technical Assessment Report page 6-14]

Such treatment is equivalent to an assumption of infinite fuel economy. Although this might initially appear to pose mathematical problems with regard to aggregating fuel economy across vehicles, it does not, as all such calculations are preformed in fuel consumption space where EVs will simply have zero fuel consumption (infinite fuel economy). It is also certainly possible that the EPA could reconsider their current zero emissions policy, but they would also have to adjust their target GHG standards accordingly -- so that the most appropriate GHG regulation-based fuel economy multiplier at this time is infinity. Aggregating this with the corrected CAFE multiplier of 12, analogous to the approach that CAR employed, would imply a net multiplier of 24. However, the most appropriate multiplier is not the average, but the minimum, as that is the value that will constrain vehicle manufacturers under equal stringency CAFE and GHG standards. Thus, the most appropriate fuel economy impact (expressed as percentage change in fuel economy) for EVs is not 600 percent as assumed by CAR, but 1,100 percent as dictated by current NHTSA CAFE rules.

The CAR fuel economy impact underestimate leads directly to an overestimation of the number and cost of EVs in any scenario for which CAR assumes a need for EV technology. Again, if the other errors in CAR's analyses are corrected, there is no scenario in the 2017-2025 Notice of Intent that would require the marketing of EVs (at least through 2025), so there is no real effect of changing the multiplier. However, this is not the case for the presented CAR estimates, where they assume an EV market share as high as 9 percent.

Slide 26 (heading: The Cost of Higher Fuel Economy)

It is somewhat difficult to comment on this slide, as it suffers from the cumulative effects of both the erroneous treatment of NAS fuel consumption impacts as fuel economy impacts (as described in detail in the section on slide 15 above) and additional erroneous effects due to the aggregation of impacts in fuel economy space rather than fuel consumption space. The net effect is a gross overestimation of the required market shares of PHEV and EV pathway technologies.

The data for the last two rows on Slide 26 appear to be expressed correctly as fuel economy impacts, but the fuel economy data in the column headed "Improvement" for the other rows are not expressed correctly. If the improper fuel consumption impacts are replaced with the correct fuel economy impact estimates, as presented in Table 1 above, and the calculations in the column headed "Contrib to FE" are replaced with appropriate fuel consumption based aggregations, the net fuel economy change is 71.8 percent. Thus, the real improvement in fuel economy is 39 percent higher than the 51.5 percent depicted on the slide.[5] A 71.8 percent change in fuel

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[5] If calculated correctly as an aggregation of fuel consumption impacts, the aggregated total of the column headed "Contrib to FE" (which should be revised to "Contrib to FC") will be 41.8 percent, reflecting a net change in fuel *consumption* of 41.8 percent. A 41.8 percent change in fuel consumption is equal to 1/(1-0.418) = 1.718, or a net change in fuel *economy* of 71.8 percent.

economy equates to a CAFE fuel economy of 47.2 mpg -- not the 41.7 mpg targeted by CAR. The market shares estimated by CAR are overaggressive and the resulting net cost much higher than a 41.7 mpg CAFE standard would dictate -- *even using the cost and impact data developed by CAR*.

Interestingly, these two mathematical errors would have cancelled each other out had it not been for the fact that the CAR PHEV and EV impacts are "correctly" in fuel economy space. Because of this, the inappropriately-based fuel economy aggregation algorithm in the "Contrib to FE" column vastly overestimates the impact of a combined 4 percent PHEV and EV market share on the aggregate change (this 4 percent market share contributes over 24 percent of CAR's estimated -- albeit erroneous -- fleet average impact). Without this inconsistency, the aggregate value in this column would have appropriately reflected the net change in fuel *consumption*, which could have then simply been inverted to get the net change on fuel economy. As it currently stands, the depicted 51.5 percent change is a meaningless hybrid of an incorrect mixture of fuel consumption and fuel economy calculations.

If the correct fuel economy multipliers for PHEV and EV technology are added to the implemented corrections, the resulting "mathematically correct" CAFE estimates are 47.6, 54.0, and 61.9 mpg for the CAR specified targets of 41.7, 49.8, and 60.1 mpg. It is obvious that CAR has significantly "overshot" their CAFE targets in all three scenarios and thus overestimated CAFE compliance costs -- even using their own data.

As indicated in their presentation, CAR predicted vehicle RPEs of $4,190, $5,223, and $6,435 for the 41.7, 49.8, and 60.1-mpg scenarios. If technology is "backed out" from the available CAR pathways to eliminate the CAFE overshoot, RPEs (for the same three CAFE scenarios) can be reduced to $2,596, $4,369, and $5,830 *without any change to the CAR cost impact estimates for individual technology pathways*. It should also be noted that not a single EV is required to meet these targets. The specific technology market shares are 33% SI-1/67% SI-2 for the 41.7 mpg scenario, 25% SI-3/75% E-2 (HEV) for the 49.8 mpg scenario, and 70% E-2 (HEV)/30% E-3 (PHEV) for the 60.1 mpg scenario, again without any change to the CAR technology estimates.

As discussed above, CAR also neglected to adjust their target CAFE standards for air conditioning system credits. To provide an indication of the cost impact associated with this oversight, a CAFE scenario that sets the 2025 CAFE target to 56 mpg (equivalent to the most stringent CAFE option in the 2017-2025 Notice of Intent) was evaluated. Under this scenario, compliance can be achieved using an 84% E-2 (HEV)/16% E-3 (PHEV) market share mix for an RPE of $5,254 (using CAR estimated cost impacts). Thus, without any change to CAR cost data, the maximum compliance RPE is reduced from $6,435 to $5,254, a net change of $1,181 (18%).

Table 4 presents the impact estimates that result from the substitution of the alternative NAS high fuel economy, low cost impact estimates into these same scenarios. Net compliance RPEs are reduced by 50-67 percent relative to the RPEs in the CAR presentation. Moreover, no PHEV or EV technology is required even under the most aggressive CAFE scenario. Note also that even the least aggressive technology pathway available in the CAR presentation results in overcompliance with CAFE under the 41.7-mpg scenario (i.e., the least advanced CAR technology pathway generates a CAFE of 42.8 mpg).

It should be noted that no attempt was made to supplement the available technology pathways with alternatives not included in the NAS/CAR analysis (e.g., cooled/boosted EGR technology for SI engines or P2 HEV technology for HEVs), The pathways included in the CAR analysis were simply reused. To the extent that the non-included pathways can further reduce compliance costs, those effects are not reflected in Table 4. Additionally, no attempt was made to perform any type of market analysis to predict actual technology penetrations. The least cost solution using the presented pathways and associated impact data were produced in an effort to determine the effective stringency of each CAFE scenario.

Table 4. Market Shares and RPEs for Alternative NAS Impact Estimates

Pathway	Technology Market Shares			
	41.7 mpg Scenario	49.8 mpg Scenario	60.1 mpg Scenario	56.0 mpg Scenario
SI-1	100.0%	0.0%	0.0%	0.0%
SI-2	0.0%	82.0%	16.0%	39.0%
SI-3	0.0%	0.0%	0.0%	0.0%
CI-1	0.0%	0.0%	0.0%	0.0%
CI-2	0.0%	0.0%	0.0%	0.0%
E-1 (HEV)	0.0%	18.0%	84.0%	61.0%
E-2	0.0%	0.0%	0.0%	0.0%
E-3 (PHEV)	0.0%	0.0%	0.0%	0.0%
E-4 (EV)	0.0%	0.0%	0.0%	0.0%
Aggregate mpg	42.8	49.8	60.2	56.1
Aggregate RPE	$1,373	$2,194	$3,235	$2,872
CAR RPE	$4,190	$5,223	$6,435	n/a
Net RPE Change	-67%	-58%	-50%	-55%

Note: The net RPE change for the 56.0-mpg scenario is expressed relative to the 60.1 CAR scenario RPE.

Slides 27-29 (heading: The Cost of Higher Fuel Economy)

These slides depict pie charts that summarize CAR's predicted market shares and aggregate RPE for each of their three CAFE scenarios. The issues associated with these estimates are discussed in detail in the section for slide 26 above. Table 4 in the section on slide 26 presents alternative market share and cost estimates.

Slide 30 (an additional introductory slide)

No comments.

Slide 31 (heading: Average Expenditure Per New Car (1967-2009))

It is appropriate to review the comments on slide 32, below, with regard to certain implications of the presented data.

Slide 32 (heading: Net Price Formula)

This slide presents the specific formula CAR uses to evaluate the potential change in vehicle price that they then subsequently use to estimate the potential impact on new vehicle sales and employment.

The inclusion of the cost of additional safety equipment mandated between now and 2025 is not appropriate from a CAFE viewpoint. Unless CAR is prepared to include an analysis of the benefits (both consumer and societal evaluations) of additional safety equipment, then including costs for such equipment (speculative or otherwise) is simply not justified. CAR does attempt to perform a cost-benefit analysis for CAFE and, thus, the other elements of their formula are appropriate – but this one-sided treatment of safety equipment only serves to artificially inflate the "apparent" costs of CAFE. Before any additional safety requirements can be imposed, NHTSA must, by law, perform an appropriate cost benefit analysis and that will the time to determine the impact of such requirements on the industry. All safety costs should be removed from this presentation unless CAR can provide for a two-sided analysis *and* refocus the presentation so that it is not portrayed as a singular indictment of CAFE.

It is also important to note that while CAR includes safety costs in their economic impact analysis of the industry, they completely ignore all "non-governmental" cost increases. As shown in slide 31, the largest growing cost increase over the last decade has been "other content" unrelated to either mandated safety or emissions. In 1997, "other content" contributed about 32 percent of the cost of a vehicle, as compared to 21 percent for safety and emissions equipment. By 2009, these percentages had become 42 and 20 percent respectively. In other words, the fraction of vehicle costs related to safety and emissions *declined*, while that related to "other content" increased by roughly one percent annually -- and *was responsible for virtually 100 percent of the increased cost of vehicles* over the 12-year period. Yet somehow this "other content" cost increase is not expected to impact vehicle sales or employment. Clearly, the implication is that the industry has performed the requisite cost benefit analysis for this content and determined that industry sales and performance will benefit despite the associated increase in vehicle cost. In effect, there is more to industry sales and performance impacts than cost and this should be considered as one evaluates the comprehensiveness of the CAR economic analysis.

Slide 33 (heading: Safety and Other Mandate Costs: 2025)

This slide presents a list of safety equipment that could be introduced over the next 15 years, and includes a completely unsupported statement on the potentially associated cost. As described in the discussion for slide 32 above, safety equipment costs (even if supported) are irrelevant without an accompanying benefit analysis. As no such analysis is included in the presentation, this slide and all other issues related to safety equipment should be removed. As handled by CAR, the sole effect of including such costs is to skew the "apparent cost" of CAFE upward.

Slide 34 (heading: Total Additional Retail Price for CAFE and Mandated Safety: 2025)

Here again, the safety costs should be removed. See the comments for slides 32 and 33 above for additional discussion with regard to the rationale for this removal.

Slide 35 (heading: Charging Equipment and Electricity Cost)

As described in the section on slide 26 above, the fraction of required PHEV and EV technology is grossly overestimated in the CAR analysis. As a result, the data on this slide are also grossly overestimated and should realistically approach zero. Even if such costs were justified, as they would be in a CAFE scenario that was sufficiently aggressive to require PHEV or EV technology, CAR has made no attempt to forecast any associated equipment cost reductions that would be expected between now and 2025. Although the tabulated values appear to be relatively minor -- even with the described shortcomings -- they more than double estimated electricity costs.

Slide 36 (heading: Consumer Present Value (PV) of Fuel Savings from Increased MPG)

On this slide, CAR presents their estimated fuel savings associated with increased CAFE. Not only do the presented values include all the errors discussed in detail in the section for slide 26, above, but also several additional errors are introduced in the calculations summarized on this slide. Taken together, these errors greatly depress the estimated value of fuel savings *for any given CAFE scenario*.

The annual mileage estimates used by CAR, 12,022-12,787 miles per year depending on the particular CAFE scenario analyzed, are substantially lower than annual mileage estimates calculated by NHTSA from available U.S. data. The NHTSA data, forecasted to 2025 (by NHTSA), indicate average mileage during the first five years of vehicle ownership (the period analyzed by CAR) to be 17,165 miles per year for cars and 19,315 miles per year for light trucks. A simple average of these data would indicate a light duty vehicle average annual mileage of 18,240 miles. This compares to an assumed CAR base mileage of 11,432 miles (as back-calculated from the rebound-adjusted CAR estimates for their three CAFE scenarios). This differential alone implies that fuel savings should be 60 percent greater -- under any scenario -- than those estimated by CAR.

Another major error is that CAR fails to make adjustments for the differential between CAFE and in-use fuel economy (this is easily confirmed since it is possible to exactly replicate their calculations using their CAFE values). If we apply a typical fuel economy adjustment factor of 0.8, then in-use fuel consumption savings will be an additional 25 percent higher than CAR estimates -- again, for any scenario. When combined with the 60 percent factor due to mileage underestimation, *estimated fuel savings over the first five years should be about twice those estimated by CAR*.

While these impacts alone have huge impacts, there are additional issues to consider with regard to the CAR estimates. First, they applied an effective rebound factor of 10 percent (expressed as change in mileage per percent change in *fuel economy*) to all CAFE scenarios, as measured from a constant 2008 baseline. There are multiple associated issues with such an assumption and application. The cost of driving is related to fuel consumption, not fuel economy, so applying a fuel economy-based rebound elasticity has two direct effects -- it masks the actual effective fuel consumption rebound rate as that rate is now dependent on baseline and scenario fuel economy and it results in a fuel consumption rebound rate that varies with scenario fuel economy (and varies such that it increases when decreases could be justified and vice versa).

Using the base and scenario fuel economy values for the CAR scenarios reveals cost per mile elasticities of -0.152, -0.181, and -0.219 for the CAR 41.7, 49.8, and 60.1 mpg scenarios respectively. Not only are these elasticities quite high, they effectively increase with CAFE when one would expect just the opposite, as incremental fuel savings decrease as fuel economy increases. There is also considerable research indicating that VMT elasticity has declined dramatically with increasing income and that, assuming economic growth continues in the future, fuel price elasticity will be at most a few percent by the 2020-2025 period -- not 15-22 percent assumed by CAR.[6]

It is also interesting to note that CAR's analyses find that increases in vehicle price will *not* be offset by savings in fuel use, yet CAR still assumes that consumers will significantly increase their annual VMT, thereby exacerbating their financial "loss" associated with the vehicle price increase. In effect, what we have is a situation where fixed costs (vehicle price changes) and variable costs (fuel expenditure changes) are treated as entirely independent so that consumers are expected to irrationally evaluate their overall transportation expenditures. This is not an area that has been studied, likely because historically the associated price increases have been small relative to the fuel savings and are effectively masked by other pricing influences. However, it could have a significant effect in cases where the vehicle price increases are large compared to the fuel savings, as assumed by CAR.

The CAR fuel savings calculations also rely on a discount rate of 10 percent and limit savings to five years of valuation. These are not unrealistic assumptions for evaluating how a consumer might respond to the potential to purchase a higher fuel economy vehicle given a specific lower fuel economy counterpart. However, there are two fundamental issues associated with the way CAR discounts savings. First, they apply the discount beginning immediately with the purchase of the vehicle. This has the effect of reducing overall fuel savings estimates by 9 percent (given a 10 percent discount rate) relative to the values that would be derived by not discounting "current year" fuel savings. Second, since mileage declines with age, CAR underestimates fuel savings by discounting average rather than actual annual mileage. Fortunately, this latest underestimation in minor -- at only about 0.2 percent -- as mileage variation during the first few years of ownership is minor.

It is important to recognize that when the CAR calculations are corrected solely for the assumed mileage differentials, in-use fuel economy adjustments, future year-only discounts, and a 3 percent (from year zero) VMT rebound rate, all three CAR CAFE scenarios have net payback periods of less than five years. *In other words, even if a consumer-based valuation of only five years of fuel savings at a 10 percent discount rate were performed while still using CAR's estimates of technology costs and benefits, the fuel savings for each scenario at the <u>lower</u> CAR-assumed fuel price of $3.50 per gallon would more than offset the CAR assumed vehicle price increases*. Table 5 presents the associated payback periods, both using the CAR technology cost and benefit assumptions and the NAS report low cost/high fuel economy assumptions. Table 5 also presents the corresponding payback periods for NAS technology pathways SI-1 and E-1 (HEV) as used by CAR. Payback periods assuming more conventional

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6 See for example, "The Rebound Effect from Fuel Efficiency Standards: Measurement and Projection to 2030," Kenneth A. Small, Department of Economics, University of California at Irvine, June 12, 2009.

societal discounts -- and higher gasoline prices as in the CAR $6.00 per gallon scenario -- would be even shorter.

Table 5. Payback Periods ($3.50 per gallon, 10% Discount)

	41.7 mpg Scenario	49.8 mpg Scenario	60.1 mpg Scenario	56.0 mpg Scenario
CAR RPE	$4,190	$5,223	$6,435	$5,254
Payback	4.0 years	4.3 years	4.8 years	4.2 years
Alt NAS RPE	$1,373	$2,194	$3,235	$2,872
Payback	1.3 years	1.7 years	2.1 years	2.0 years

NAS Pathway	Avg NAS FE Avg NAS RPE Payback	High NAS FE Low NAS RPE Payback	High NAS FE Avg NAS RPE Payback	
SI-1	2.8 years	1.3 years	2.2 years	
E-1 (HEV)	4.2 years	2.4 years	3.0 years	

Notes: The CAR RPE estimate for 56.0-mpg scenario is estimated from that for the 60.1 CAR scenario (the payback period for the scenario is shorter than that for the 49.8 mpg scenario because the technology mix has been established based on a least cost solution, unlike the technology mix developed by CAR).

The CAR RPE uses CAR's fuel economy impact assumptions, less the cost of safety equipment

The Alt NAS estimates are for NAS low cost/high fuel economy impact assumptions.

Slide 37 (heading: Net Price Calculation)

This slide presents a table that is simply collecting the results from slides 34, 35, and 36. As such, the comments for those slides apply here as well.

Slide 38 (heading: Net Price Increase and % Change in Vehicle Net Price)

This slide presents a table that further aggregates the data presented on slide 37. As described in the discussion for slide 36 and reflected in the less than 5 year payback periods summarized in Table 5 of that same section, the net costs for all six entries in the table on slide 37 should be negative, *implying a net decrease in fixed plus variable cost, even over just 5 years*. It is interesting to note that CAR does recognize the importance of working with net cost effects in estimating the overall net economic impacts of CAFE, but not in determining whether VMT rebound is appropriate.

Slide 39 (an additional introductory slide)

No comments.

Slide 40 (heading: Economic Model and Assumptions)

This slide defines various assumptions used by CAR in their economic analysis to estimate the impacts of net vehicle price changes on the automotive industry. Since the net vehicle price for the first 5 years of ownership has been shown to decrease for all three CAR CAFE scenarios, as discussed in the sections for slide 36 and 38 above, there is no need to assess these assumptions.

Slide 41 (heading: Effect on U.S. Vehicle Sales, Production …)

This slide summarizes CAR's estimated economic impacts on the automobile industry that would accrue due to CAFE. CAR predicts substantial decreases in vehicles sales, production, and employment -- based on significant forecasted increases in net vehicle price. However, since the correct net vehicle price changes have been shown to be negative for all three CAR CAFE scenarios, as discussed in the sections for slide 36 and 38 above, the estimated impacts presented on this slide are not accurate. In fact, given that net vehicle price changes are actually negative, it would follow that if CAR properly revised their economic analysis, all related economic impacts would be positive -- *sales, production, and employment would increase*.

Slide 42 (heading: Net Vehicle Price Change Percentages …)

This slide is simply highlighting results that are also presented on slide 41. As such, the comments for that slide apply and no further comment is needed.

Slide 43 (heading: What Controls Vehicle Age? Price and Durability …)

The implication of this slide is that CAFE-related price increases will depress industry sales, essentially reiterating results that are presented on slide 41. As such, the comments for that slide apply and no further comment is needed.

Slide 44 (heading: A Cuban Auto Syndrome?)

This slide presents a summary listing of the estimated potential cumulative impacts of higher CAFE requirements as analyzed by CAR. The inaccuracy of the assumptions underlying the various predictions has been described in detail, above. As a result of the underlying inaccuracies, the presented predictions themselves are thoroughly inaccurate. As stated several times above, a properly reconfigured CAR economic analysis should, in fact, predict positive industry impacts.

But what is disturbing about this slide is the title implication, namely that some type of Cuban vehicle market will evolve from overly aggressive CAFE policy. Cuba has been subject to a restrictive U.S. trade embargo for over 50 years and trade agreements with the former Soviet Union essentially ended with the dissolution of that union in 1989. *There is no lack of demand for vehicles and vehicle parts in Cuba*. There is a dire lack of supply, exacerbated by an unproductive Cuban economy that does not leave citizens with resources sufficient to purchase new vehicles from independent trading partners. It is a mismatch between global prices and Cuban income that is the root of Cuba's automotive "innovation." If this is the only potential comparative "outcome" CAR can find for a system of CAFE standards gone wild, it suggests that CAR is not being objective on this issue.

Slide 45 (heading: If We Downsize as Well . . . Segment Size, MPG and Price)

The purpose of this slide is not clear. Based on the presented data, the cost of increases in fuel economy through downsizing from a large car to a small car are about -$1,600 per mpg, and from downsizing from a large crossover vehicle to a small crossover vehicle are about -$2,150 per mpg. However, it suggests that CAR does not understand how the footprint attribute system works. The attribute adjustments assign each manufacturer a unique CAFÉ standard, based upon the manufacturers average footprint and mix of cars and light trucks. If a manufacturer makes more small cars and fewer larger vehicles, the attribute system simply assigns the manufacturer a higher mpg target to meet. The standards are not any easier to meet, thus there is no effect on the cost of complying with the standards. Slide 45 suggests that CAR does not understand this very basic concept.