Comments on the Draft Technical Assessment Report for Model Years 2022 – 2025 Greenhouse Gas Emission and Fuel Economy Standards

Submitted by:

Minnesota Corn Growers Association
Minnesota Corn Research and Promotion Council and the
Illinois Corn Growers Association

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Dockets

For the US Environmental Protection Agency:	EPA-HQ-OAR-2015-0827
For the National Highway Traffic Safety Administration:	NHTSA-2016-0068
For the Federal Register:	FRL-9949-54-OAR

Early this year, the Minnesota Corn Research and Promotion Council approved a research grant to Defour Group LLC (D4) and Air Improvement Resource INC (AIR) to download the publically available OMEGA computer model developed by the US Environmental Protection Agency. Once downloaded, the researchers were asked to use that mode to, estimate the impact of a combination of high octane low carbon (HOLC) fuel and high compression engines (HCE) on the cost to consumers of complying with the 2022 – 2025 greenhouse gas emission standards. This study concluded that such technology could reduce the cost of the average MY 2025 vehicle by over $400.

The Draft Technical Assessment Report concerning these standards was the beginning of the agencies' mid-term evaluation process, which, among other things, is to consider "*technical and other analyses and projections relevant to each agency's authority to set standards as well as any relevant new issues that may present themselves*." We believe the research done by AIR and D4 is the kind of analyses the agencies intended to consider during the mid-term review process, Therefore, these comments and the supporting attachments are hereby being submitted to the docket for your consideration.

The original rulemaking for these standards were issued in 2012 to guide the development of motor vehicle design for the next 13 years. Because of the long timeframe, the agencies established the process for a mid-term review including a draft technical assessment report to be issued no later than November 15, 2017. This assumed date guided the planning for a great deal of research in many different industries. The nearly unprecedented issuing of this draft report over a year before it was required left a great deal of research on-going when the report was issued. Furthermore, parties were given only 60 days to prepare their comments regarding this draft report. For these reasons, we urge the agencies not to finalize the Technical Assessment Report until at least the November 15, 2017 date. Also, we ask that the agencies allow additional new research and updates to be submitted to the docket at any time following the end of the formal submission period.

Comments on the Draft Technical Assessment Report for Model Years 2022 – 2025 Greenhouse Gas Emission and Fuel Economy Standards

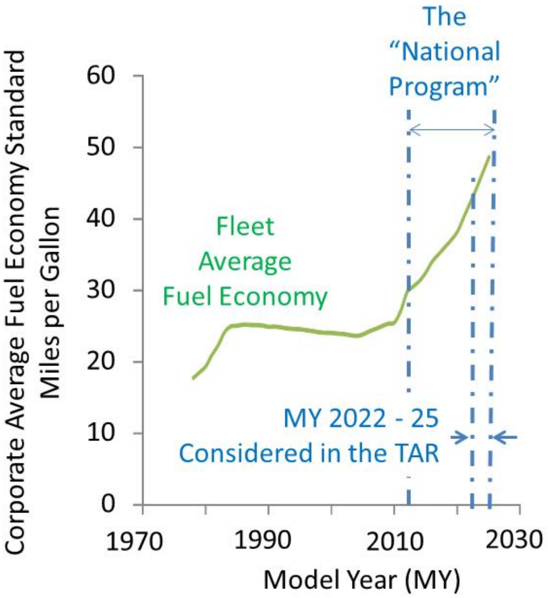

Figure 1. History of Fuel Economy Standards

The Draft Technical Assessment Report (TAR) was prepared by the US Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) in cooperation with the California Air Resources Board "*to examine afresh the issues* [relevant to the MY 2022 – 2025 standards] *and, in doing so, conduct similar analyses and projections as those considered in the current rulemaking, including technical and other analyses and projections relevant to each agency's authority to set standards as well as any relevant new issues that may present themselves.*"[1] The 2022 – 2025 MY standards for tailpipe greenhouse gas emissions and corporate average fuel economy were part of a rulemaking package issued in 2012 covering the 2017 – 2025 model years, which in turn followed standards issued two years prior for the 2012 – 2016 model years. The standards being evaluated in the TAR are the last three years of a 14-year effort (referred to as the "National Program") to reduce greenhouse gas emissions and increase the fuel economy of light duty vehicles, as shown in Figure 1. As such, they can be considered both the final part of a very ambitious program as well as the foundation for the next chapter of the national program.

One of the "relevant new issues" that has emerged since 2012 has been the potential to reduce greenhouse gas emissions by a combination of higher efficiency spark ignition engines and a high octane low carbon (HOLC) fuel such as a 25% ethanol – 75% gasoline blend called E25. As discussed in the TAR[2], the Department of Energy (DOE) is conducting a program called Co-Optima (Co-Optimization of Fuels and Engines) that intended to determine *"improving near-term efficiency of spark-ignition (SI) engines through the identification of fuel properties and design parameters of existing base engines that maximize performance. The efficiency target represents a 15% fuel economy improvement over state-of-the-art, future light-duty SI engines with a market introduction target of 2025 … By using low-carbon fuels, such as biofuels, GHGs and petroleum consumption can be further reduced."*

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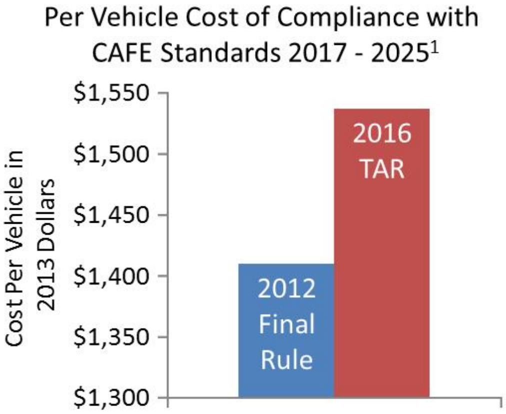
[1] Draft Technical Assessment Report, pg. I-2

[2] Ibid. Page 5-42.

Co-optimizing fuels and engines or the ongoing process of research and development of technologies in the auto industry and the national laboratories clearly offer the potential to reduce greenhouse gas emissions using methods and applications of technologies that were not comprehended in the original rulemaking. Past evaluations[3] indicate that a combination of higher compression engines and a lower carbon fuel could achieve these standards at much lower cost than many of the strategies considered for the 2017 – 2025 timeframe. Thus, it is essential to include detailed discussion of this concept, including the results from industry research, DOE's Co-Optima program and other new information, in the final version of this TAR.

The Issue of Ever-Declining Cost Effectiveness of More Stringent Standards



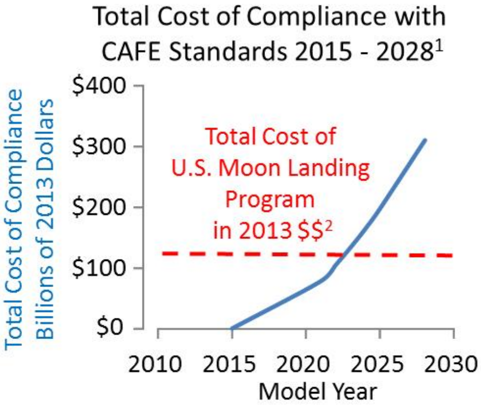
1 Table 13-93 Technical Assessment Report with 2012 costs adjusted by CPI to 2013 $$

Figure 2. The Increasing Cost of Compliance

The total cost to the automotive industry to comply with these standards is increasing as well. As shown in Figure 3, NHTSA estimates that the cumulative cost to the automotive industry will be an astounding $311 billion to increase the fuel economy of light duty vehicles from 2015 to 2028 (in 2013 dollars)[5]. By comparison, it is estimated that the US only spent $122 billion in 2013 dollars in its program to land humans on the moon.

The impact of 2017 – 2025 greenhouse gas emission and fuel economy standards on the price of new cars and trucks is now estimated to be much greater than it was in the original rulemaking.

In the TAR, NHTSA shows the cost per vehicle of complying with the 2025 MY Corporate Average Fuel Economy (CAFE) standards vs the 2017 standards[4] (See Figure 2). Between when the 2025 MY CAFE standards was first enacted and today, the average compliance cost per vehicle has increased by $120 per vehicle.



1 Table 13-21 Technical Assessment Report
2 Cost from NASA Testimony to 93rd Congress, (adjusted by CPI)

Figure 3. Industry-Wide Costs Rising Past 2025

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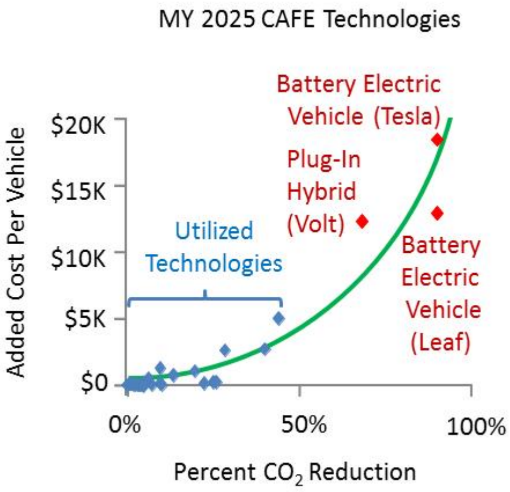
[3] e.g., the report prepared by the Defour Group for the MN Corn Research and Promotion Council entitled "The Economics of Eco-Performance Fuel," Dean Drake et al, April 22, 2014 indicated that with a mid-level blend fuel and high compression engines, consumers would pay $523 less per vehicle in 2025.

[4] Data from Table 13-93 Technical Assessment Report with 2012 costs adjusted by CPI to 2013 $$

[5] Data from Table 13-21 Technical Assessment Report

The law of increasing marginal cost, which says that each succeeding increase in the stringency of a standard will come at a higher price than before, explains these increased costs. This occurs because manufacturers will first employ and fully utilize technologies with the lowest cost per unit of improvement before adopting more expensive and complex technologies. This is illustrated in Figure 4.



Data From Final Regulatory Impact Analysis, NHTSA, August, 2012

Figure 4. Fuel Economy Cost Curve

Relatively low cost technologies like low friction lubricants and tires are already widely used in the 2015 model year, as are some higher cost technologies such as variable valve timing. By 2022, the beginning of the period being evaluated in the TAR, manufacturers will have fully utilized many of the low cost technologies and will depend increasingly upon new, higher cost and more complex technologies such as hybrid electric vehicles.

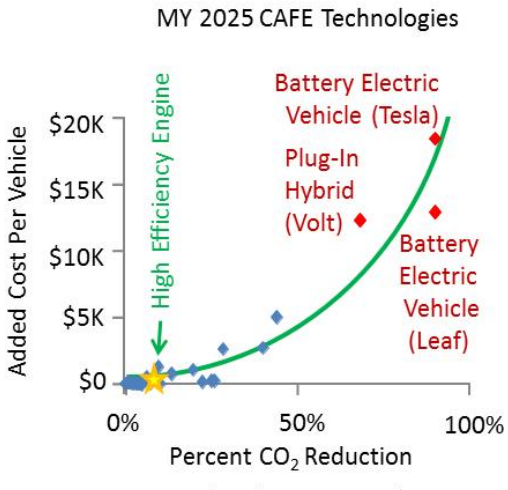
The increasing cost of ever more stringent standards is clearly a problem for automobile manufacturers and consumers in the 2022 – 2025 timeframe. In addition, this trend of ever-higher costs and new vehicle price increases will be even worse after 2025 if the standards are made more stringent.

The agencies' evaluation of the cost and feasibility of the 2022 – 25 fuel economy and greenhouse gas standards is not only an evaluation of the last years of the current years of the national program, but also of the feasibility of enacting more stringent standards after 2025. As such, the escalating costs and declining benefits of more stringent standards utilizing the technologies considered in the TAR should be addressed in the TAR.

Lowering the Fuel Economy / Greenhouse Gas Emissions Cost Curve

If a relatively low cost technology not currently employed were introduced to the cost curve, however, that technology could be employed to meet more stringent standards without raising the price of new vehicles. High efficiency engines enabled by reasonably priced, higher octane - lower carbon fuel is such a disruptive technology. This is illustrated in Figure 5.

Under this scenario, manufacturers could increase the compression ratio of their spark ignition engines significantly, thus improving the engine's thermal efficiency. The cost of doing so would be minimal: compression ratio is a function of the basic design of the engine and does not require additional hardware.



Data From Final Regulatory Impact Analysis, NHTSA, August, 2012

Figure 5. Adding a Low Cost Technology

Universally available high octane fuel would prevent engine knock in these higher compression engines. If one of the high octane fuels were an ethanol blend fuel such as E25, consumers would pay no more at the pump for higher octane fuel than they do today for regular grade gasoline.

The combination of a universally available, reasonably-priced, higher octane fuel such as E25 and higher efficiency spark ignition engines would present a lower cost alternative to many of the technologies that the agencies foresee being employed to meet the 2022 - 25 standards. It is expected that vehicle manufacturers would begin revising their product plans to replace higher cost compliance technologies with lower cost, higher efficiency engines once they were certain that low octane regular gasoline would be off the market and replaced with a similarly priced high octane gasoline ethanol blend.

This would both lower the cost of compliance for model years in which more efficient engines would be employed and allow the displaced technologies to be utilized in later model years. As a result, the cost of compliance with the standards in 2022 and beyond will be reduced, thus reduce the escalating burden of these standards on consumers.

Estimating the Cost of the 2025 Greenhouse Gas Emission Standards

In theory, adding a new lower cost technology to those already being considered in the TAR should lower the cost of compliance with the standards as manufacturers displace more expensive technologies with the new less expensive technology. Estimating how much the compliance cost can be reduced, however, is not straightforward.

In developing the cost effectiveness values for the TAR, the agencies employ two mega-models that simulate the compliance decisions manufacturers make regarding the various ways to improve vehicle fuel economy and reduce greenhouse gas emissions. The NHTSA uses the Volpe model designed to simulate how manufacturers would improve fuel economy to comply with the Corporate Average Fuel Economy (CAFE) standards. The US EPA uses the OMEGA model to simulate how manufacturers could comply with the greenhouse gas tailpipe emission standards.

To project the impact of adding higher compression, more fuel-efficient engines and low cost, lower carbon, higher octane fuel to the available technology mix on the overall cost of compliance, some such simulation model should be used. After evaluating both models, Air Improvement Resource INC (AIR) elected to download the OMEGA model[6] and, with the assistance of EPA staff, duplicated the cost of compliance that EPA used in the TAR.

As described by EPA in the TAR[7], *"The OMEGA model is designed to estimate the cost of complying with a standard (or target) in a given future year[8]."* EPA further states: *"The wide number of technologies that are available, and likely to be used in combination, requires a method to account for their combined cost and effectiveness, as well as estimates of their availability to be applied to vehicles. As done in*

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[6] The study done by Air Improvement Resource was done with a research grant from the Minnesota Corn Research and Promotion Council.

[7] Draft Technical Assessment Report, page 12-3

[8] Ibid. Page. 12-2

establishing the GHG standards for MY2012-2016 and 2017-2025, EPA is using a computerized program called the Optimization Model for reducing Emissions of Greenhouse gases from Automobiles (OMEGA). Broadly, OMEGA starts with a description of the future vehicle fleet, including manufacturer, sales, base CO2 emissions, vehicle footprint, and an assessment of which GHG emissions-reducing technologies are already employed on the vehicles. For the purpose of this analysis, EPA uses OMEGA to analyze roughly 200 vehicle platforms which encompass approximately 1,300 vehicle models to capture the important differences in vehicle and engine design and utility of future vehicle sales of roughly 15-17 million units annually in the 2021-2025 timeframe. … The result is a description of which technologies could be added to each vehicle and vehicle platform, along with the resulting costs and achieved CO2 levels."

The study performed by Air Improvement Resource, "Evaluation of Costs of EPA's 2022-2025 GHG Standards with High Octane Fuels and Optimized High Efficiency Engines", is Attachment 1 to these comments. The AIR study involved:

- Downloading the publicly available OMEGA computer model and replicating the estimated cost of compliance with the 2025 MY greenhouse gas emission standards that EPA reported in the TAR. This not only involved downloading the program from EPA's website, but also working with EPA staff to learn what else was required, including obtaining the latest version of the model and various program operational details. Once up and running, AIR validated the model by replicating the costs of compliance that EPA had estimated for the final rule and the TAR.
- Estimating, based on the best publicly available information, the cost of increasing the compression ratio of spark ignition engines and the fuel economy and emission benefits attainable using a 25% ethanol – gasoline blend (E25) with a research octane number of 98 (98 RON). Three Society of Automotive Engineers (SAE) reports, the 2015 National Academy of Science study, an article for the journal "Environmental Science and Technology" and a 2016 study by the Oak Ridge National Laboratory were analyzed to estimate the potential CO2 reductions and technology costs and CO2 benefits of a technology package that combined high compression ratio engines (HCE) with a high octane low carbon (HOLC) fuel[9]. Based on the review of relevant information, AIR concluded that the cost of modifying a spark ignition engine to increase its compression ratio to take advantage of the higher octane fuel would be $100 per vehicle.

  No test results were available for E25 HOLC fuel to use to estimate the CO2 reduction benefits. Therefore, AIR needed to derive the values from testing done on a variety of fuel blends ranging from E20 to E30. According to the study, *"Most of the previous studies indicated a GHG emissions reduction in 4-8% range for E20-E30 fuels with RONs of 96-101. In this study, we will base our estimate of the GHG emissions reduction on the 2015 ES&T paper, which developed comprehensive impacts for a 96-RON E20 and a 101-RON E30. The tailpipe GHG emissions change for a 98- RON E25 would be one-half of the reductions of these two fuels, or 5.75%. We will round this to 6%[10]"*

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[9] Citations and a more complete description for these sources can be found in the attached report.

[10] "Evaluation of Costs of EPA's 2022 – 2025 GHG Standards with High Octane Fuels and Optimized High Efficiency Engines," Air Improvement Resource, page 9.

Vehicle testing is currently underway at ORNL to evaluate the fuel economy and CO2 emission benefits of E25 high octane mid-level ethanol blend fuel with a high compression ratio engine and simulated downsized and downspeeded vehicle configuration. Preliminary data appears to demonstrate the benefits of the technology that are consistent with the AIR analysis of benefits and costs[11]. Complete results are expected to be available sometime in 2017.

- Estimating the cost of future E25 fuel using data from the Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2015. While any of the technology paths included in the TAR raise the cost of a new vehicle, they also impact fuel economy and the amount consumers pay for fuel. Similarly, a change in the fuel required to operate the vehicle will impact fuel costs. When EPA used its OMEGA model to calculate the cost of compliance with the 2025 standards for the TAR, they calculated the resulting fuel savings based on the fuel prices forecast in AEO 2015. For purposes of the AIR analysis, it is important to forecast the price of regular grade 87 AKI E10, premium grade E10 and HOLC fuel (in this case, a mixture of 25% ethanol and 75% regular grade gasoline blendstock – E25 - with a resulting RON of 98, similar to today's premium grade E10 gasoline. Using the AEO 2015 forecast for the prices of ethanol and E10 (all grades) and the average markup from wholesale to retail, forecasts for the prices of E10 regular, E10 premium and E25 were estimated for years 2013 – 2040.

  AIR determined that the lifetime fuel savings of $132.23 over the lifetime of the vehicle virtually cancels out the cost of increasing the compression ratio of spark ignition engines. Therefore, for purpose of its analysis, it could be assumed that there are no per-vehicle costs and no fuel savings, thus simplifying the modifications that need to be made to the OMEGA model. The report says[12] "*we are assuming a $100 cost for increasing compression ratio of vehicles. However, the lifetime PV fuel credit (using 7% discount rate) in section 3.2.1 is $132.23. For fuel distribution cost, assuming a 0.4 cent per gallon cost, the lifetime PV cost (assuming 7% discount) is $13.22. The costs and credits approximately balance each other, therefore for the remainder of this analysis we are estimating zero net cost to the consumer.*"

- Modifying the model to include higher compression engines and higher octane E25 fuel. When EPA uses its OMEGA model, it modifies the technology packages being evaluated with other programs, including an input program called ALPHA. Not having the ALPHA model, however, presented an obstacle to the researchers. "*Our first thought was to introduce HCR in the OMEGA model as a new, single technology. However, this technology would not have been recognized by the model and integrated into the existing technology packages without extensive work, so we had to develop an alternative solution*[13]. The solution that the researchers devised was to assume that all technology packages with spark ignition engines would take advantage of widely available higher octane fuel

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[11] Evaluation of Costs of EPA's 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines, AIR, Inc., September 14, 2016

[11] "Evaluation of Costs of EPA's 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines," AIR, Inc. September 10, 2016, Page 14

[13] Ibid. Page 16

and incorporate higher compression engines. Under this assumption, the CO2 emissions of each spark ignition technology could be adjusted to reflect the benefits of operating on a higher octane, lower carbon fuel. As stated in the attached report[14]:

> *"While it was necessary to make some simplifying assumptions to utilize the OMEGA model to obtain these results, we are confident that, if EPA had included this technology package in their OMEGA modeling for the mid-term review, they would have observed similar cost savings for the 2025 model year."*[15]

- Estimating how much higher compression engines and E25 fuel would have reduced EPA's projected cost to comply with the 2025 model year had that technology package been included in the TAR. After appropriately modifying the OMEGA model to reflect the emission reduction potential of higher compression engines and higher octane, lower carbon fuels (HCE + HOLC), the OMEGA program was run. The vehicle compliance costs for 2025 MY vehicles vs. a baseline of 2014 MY are shown in Figure 6. Adding HCE + HOLC to the available technology choices reduced the cost of the average 2025 light duty vehicle by $404. For some vehicles, however, the cost saving was even greater. For instance, a Buick Enclave (typical of highly popular crossover SUVs with three-row seating) was reduced by $873.

  The researchers added an important caveat to these results. *"It should also be noted that this analysis was performed to predict what EPA would estimate the potential cost-savings of this new technology would be in 2025. Therefore, we have retained the same assumptions regarding costs as EPA has used. Others, however, calculate costs differently. NHTSA, for example, estimates costs using the Retail Price Equivalent Method of mark-up, while EPA retains the use of the Indirect Cost Multiplier method. The NHTSA methods result in higher compliance costs than EPA. Therefore, it is quite possible that the actual cost savings will be much greater than the numbers predicted in this study."*

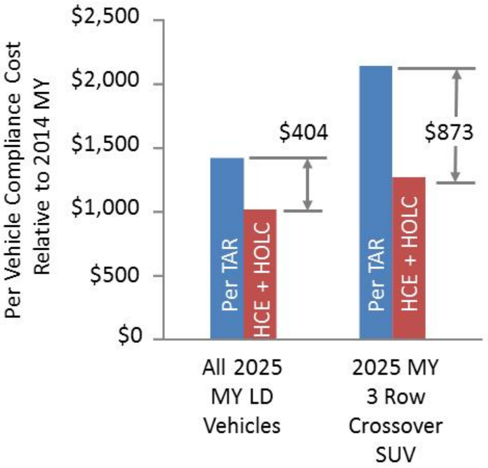

Figure 6. Cost Impact of High Compression Engines and High Octane Low Carbon Fuel (HCE + HOLC)

Based on this study, it can be concluded that universal availability of a 98 RON, E25 would create the incentive for vehicle manufacturers to increase the compression ratio on most of their spark ignition vehicles, thereby improving thermal efficiency and reducing CO2 emissions. By reducing manufacturers reliance on more complex and expensive technologies to achieve the same emission reduction goals, the cost of the average new MY 2025 vehicle could be reduced by $404. Furthermore, the cost impact of some vehicles, such as popular crossover SUVs with three row seating could be reduced by $873.

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[14] Ibid, Page 18

[15] Ibid. Page 20

Who Would Benefit from these Cost Reductions?

The cost reductions discussed above are significant to the overall economy. Assuming the 15 – 17 million units per year sales of LD vehicles incorporated in the OMEGA model, the $404 reduction in the price of a new MY 2025 vehicle translates into $6 - $7 billion dollars a year, without even considering that lower vehicle prices might result in increased vehicle sales. Given that cost savings of this magnitude should persist in future model years as well, consumers could possibly save $60 - $70 billion dollars over a decade.

Certainly the general public would benefit from the engine technology enabled by universally available, higher octane fuel that costs the same or less than today's regular. For some groups within the general public, however, these savings would be even more significant.

Low Income Households: Low income households depend even more on the personal mobility that automobiles represent than the general public does. In comments submitted to the agencies during the original rulemaking, Dr. Thomas Walton of the Defour Group stated:[16]

"A recent study by Professor Mark Jacobsen (University of California at San Diego) found that fuel economy standards are "sharply regressive" and that the costs of fuel economy mandates "fall disproportionately on low-income households." He found, for example, that "low-income households" buying ten-year-old vehicles are "suffering welfare losses (as a fraction of income) more than three times as large as those of the high-income group. … This finding is important because used cars play an essential role in the escape from inner-city poverty. Studies show that car ownership rates are lower among minority groups, and this appears to be a significant factor in explaining the lower employment rates of these groups. A study conducted by researchers at the University of California at Berkeley estimated that raising minority car ownership rates to the white car ownership rate would eliminate 45 percent of the black-white employment rate differential and 17 percent of the comparable Latino-white differential. By raising the cost of vehicle ownership, fuel economy standards work in precisely the opposite direction."

The availability of lower-cost used vehicles and an affordable higher octane gasoline would benefit low income households in two ways. First, the lower cost and less complex technology of higher compression spark ignition engines would reduce the cost to purchase and maintain the vehicles typically purchased by low income households; i.e., vehicles near the end of their useful lives. Often, these households are limited to the cars they can choose from due to credit issues: even a few hundred dollars in lower purchase price would allow a low-income purchaser to qualify to buy a car with more useful life. Also, the anticipated maintenance costs for the less complex, higher compression engines could be much less at very high mileages than the cost to maintain the more complex technology that is displaced.

Furthermore, the use of ethanol to raise the octane floor on gasoline rather than hydrocarbons would result in significant fuel savings as well. The AIR report attached to these comments looks at the cost to

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[16] "Comments on the Preliminary Regulatory Impact Analysis for MY 2017 to 2025 Fuel Economy Standards," February 13, 2012, Page 10

use today’s E10 premium fuel rather than E25 on what consumers would spend during their vehicles’ lifetime. The authors reported:

“We do not evaluate the impacts of a premium fuel on compression ratios and overall program costs. The main reason for this is cost – the current price differential of premium over regular in the US is about $0.26/gallon. Using EPA’s mileage accumulation rates for passenger cars, an assumed fuel economy of 45 mpg, and a 7% discount rate, the net present value of the fuel costs is $860, close to the average new vehicle cost in the TAR.[17]”

Clearly, the combination of higher compression engines and higher octane, lower carbon fuels would have a positive impact on the lives of low income households.

Farmers and Businesses: The 9-year span of the current GHG and fuel economy regulations that culminate in the standards being considered in the TAR is just beginning. It is far from clear what the technologies and available models might be in the later years of this program. An automotive engineer stated in the periodical Automotive Engineering, *“Tellingly, of the 3% of the 2015MY fleet that meets the 2025 standards, all employ hybridization or full electrification. Not a single 2015 conventional gasoline or diesel vehicle is yet 2025 compliant.”*[18] In other words, the only propulsion systems assured a place in the fleet in nine years’ time involve some sort of electrification. Even with another nine years’ leadtime, some types of vehicles that we know today cannot be electrified.

1976 Chevrolet Impala

2016 Chevrolet Impala

Figure 7a. Passenger Cars Since 1976

Smaller commercial vehicles used throughout the country are good examples of current vehicles at risk of disappearing or having degraded capability. Specifically, these are pickup trucks and light duty vans used in urban areas for delivery or services and in rural areas by farmers and others who work in agriculture. These types of vehicles:

- Are not easily downsized. Since the first fuel economy standards were enacted in 1976, passenger cars have been made smaller and lighter over time without sacrificing passenger space or utility by converting to front wheel drive and shifting to unit construction (see Figure 7a).

  Work vehicles, however, are locked into specific size and hauling requirements. The standard light-duty pickup truck, for example, must carry a given payload (1 to 1½ tons) and have a bed large enough to haul 4’ X 8’ sheets of plywood or drywall. These trucks must have the torque and horsepower to pull large trailers. While engineers can use lighter weight materials and smaller engines with sufficient power, there are limits.

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[17] “Evaluation of Costs of EPA’s 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines,” AIR, Inc. September 10, 2016, Page 2

[18] “Solving the GHG puzzle,” Automotive Engineering, September, 2016, page 21.

As a result, the pickup trucks and delivery vans of today are very similar to those of 1976. The basic pickup truck (Figure 7b) still utilizes full frame rather than unitized construction for load bearing and towing reasons. For load carrying and traction, they still have front engine, rear wheel drive powertrains. While passenger cars have gone from V-8 to V-6 and L-4 engines, pickup trucks still require V-8 or turbocharged V-6 engines. These requirements will not change in the next nine years.

1976 Chevrolet Pickup

2016 Chevrolet Pickup

Figure 7b. Pickup Trucks Since 1976

- Must be able to operate for long hours at a time. Work trucks used to haul materials and make deliveries generally operate throughout the workday and require long operating range. Trucks used by farmers often travel hundreds of miles per trip going from farm to city and back. The batteries used in electric vehicles either have inadequate range or excessive weight or both. Compressed natural gas offers one option, but experience severe penalties in range, space utilization ("packaging") and weight.
- Are often owned by small businesses operating on slim profit margins. Small businesses such as contractors and homebuilders, who were so hard hit in the Great Recession often compete against much larger enterprises and, lacking economies of scale, operate on very small profit margins. Similarly, small farms are dependent upon affordable work trucks. Like low income households, these businesses are very sensitive to the purchase price and operating costs of the vehicles they must have to survive. While some have argued that these owners could shift to heavy duty work vehicles that are subject to less stringent emission and fuel economy standards, this would come at a cost to both the owners and the environment.

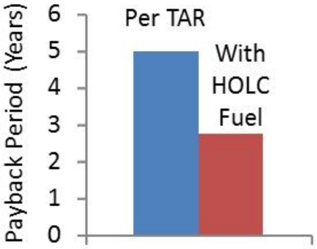

Figure 8. Change in Payback Period With High Octane Low Carbon Fuel

Enabling HCE and HOLC fuels would help keep the traditional work vehicles needed by farmers and small business owners viable through and beyond the 2025 model year[19]. As shown in Figure 8, the cost savings from HOLC fuel and high octane engines would reduce the payback period of five years predicted by EPA to three years[20]. Farmers and small businesses would still be able to get affordable light duty work vehicles that meet their needs, and they would be able to fuel these vehicles for perhaps even less per gallon than they are today.

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[19] Further study and quantification of the benefits of continued use of liquid fuels (abet with lower carbon emissions) in work vehicles is being planned.

[20] Payback period based on Table 12.54 of the Technical Assessment Report, page 12-44 and the $404 per vehicle savings estimated by Air Improvement Resource.

Why Should the Technical Assessment Report Include HOLC Fuels?

There is growing awareness that the octane of the fuels used in the US, Canada and Mexico needs to be raised to enable widespread use of higher compression, higher efficiency spark ignition engines that, in turn, can make achieving the greenhouse gas emission and fuel economy standards less costly.

At a recent seminar in Traverse City, MI, executives from the automotive industry discussed the need to raise the minimum octane rating of gasoline. *"Dan Nicholson, of Global Propulsion Systems at GM and Robert Bienenfeld VP of Environment and Energy Strategy at American Honda, agreed that the industry must push for a higher fuel-octane 'floor' in the U.S. … 'Fuels and engines must be designed as a total system. It makes absolutely no sense to have fuel out of the mix of engine technology discussions* [Nicholson] *asserted."* [21]

Today's premium-grade E10 gasoline is a widely available (if little used) high octane fuel, but at 25 to 30 cents a gallon more than regular, is too costly for automotive manufacturers to require most of their customers to use. Ethanol, on the other hand:

- Is the lowest-cost octane-boosting compound available for gasoline and can be used to boost the octane rating of today's regular grade gasoline to the 98 RON level that automotive engineers believe is the optimum for spark ignition engines.
- Produces at least 20 percent less lifecycle greenhouse gas emissions than gasoline[22].
- Boosts the octane of gasoline without increasing toxic emissions, unlike the hydrocarbon compounds used to make today's premium gasoline.

As shown in Attachment 1, a High Octane-Low Carbon (HOLC) fuel using ethanol can significantly reduce the cost of compliance with future standards and reduce greenhouse gas emissions both from the tailpipe as well as help de-carbon the fuel itself. In addition, new research indicates that HOLC fuel can enhance the performance of technologies that are discussed in the TAR: specifically cooled EGR. The TAR_ implies that cooled EGR (cEGR) alone could be employed instead of high octane fuel as a means of controlling engine knock in downsized, boosted engines operating at high compression ratios and high loads[23]. As discussed in Attachment 2 of these comments, recent research, however, points out that even this technology gives even greater reductions in greenhouse gas emissions when operated using HOLC fuel.

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[21] "Solving the GHG puzzle", Automotive Engineering, September, 2016, page 14

[22] There is a body of evidence indicating that when EPA updates its 2010 Lifecycle Analysis, the results will show that ethanol blend fuels reduce greenhouse gas emissions substantially more than the 20 percent figure EPA is currently using.

[23] "Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025," U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, California Air Resources Board, July 2016, Sec. 5.2.2.8 to 5.2.2.9

HOLC fuel is a strategy that can be implemented in the time frame being considered in the TAR. One of the arguments against including discussion of HOLC fuel in the TAR is that it cannot be implemented within the next nine years. It is true that past changes in fuels have taken longer -- leaded gasoline was not fully phased out of the fuel supply until 14 years after Congress demanded the removal of lead from gasoline. A long lead time was required to remove lead from gasoline because it involved a complete modification of the gasoline production and distribution system from the refinery to the gasoline nozzle to the design of fuel filler inlets.

However, with the cooperation of the relevant regulatory agencies, replacing today's regular grade gasoline with higher octane E25 should be a much shorter process. Ethanol is currently added to a gasoline at blending terminals, not at refineries; therefore, refineries would remain largely unaffected. It would be relatively straightforward for the terminals to add 25% ethanol to the gasoline blendstock instead of 10%. When E10 regular-grade fuel is to be phased out of the fuel supply, gasoline stations would simply substitute higher octane E25 regular for it. Instead of the three grades of gasoline commonly offered today that are differentiated by octane rating, gasoline stations would have two blends of same (but higher) octane gasoline – E25 and E10 – differentiated by ethanol content. Vehicles not designed to operate on E25 would have E10 available for the indefinite future.

The so-called "misfueling" issue would be handled in the same way that E15 fuel is handled in the several mid-western states where it is sold today; appropriate signage would simply be required on the fuel dispenser pumps to direct the consumers to the right ethanol blend for their vehicle.

The biggest obstacles to implementing this change in fuel are regulatory ones. If the issue of HOLC fuel were made as part of the mid-term review process, this fuel could be available at retailers within nine years, thus putting it within the timeframe being considered in the TAR[24]. With positive action by the agencies during the mid-term review process, this timetable to implement E25 could even be shorter.

HOLC fuel is the most cost-effective new alternative. The TAR itself describes its mission "*to examine afresh the issues … including technical and other analyses and projections relevant to each agency's authority to set standards as well as any relevant new issues that may present themselves*[25]*.* The report by Air Improvement Resource, Attachment 1 of these comments, is one relevant technical analysis that is hereby presented, and the work of the Co-Optima team will be another. The draft TAR has been issued over a year earlier than regulations required: therefore, it is reasonable to keep the TAR in draft form (at a minimum) to the latest date at which the draft could be released: i.e., until November 15,

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[24] In the Draft Technical Assessment Report, pg. I-2, in discussing the Co-Optima [project, the agencies state "*improving near-term efficiency of spark-ignition (SI) engines through the identification of fuel properties and design parameters of existing base engines that maximize performance. The efficiency target represents a 15% fuel economy improvement over state-of-the-art, future light-duty SI engines with a market introduction target of 2025"*

[25] Draft Technical Assessment Report, pg. I-2

2017.[26] There is clearly adequate time for the agencies to consider the reports submitted as comments to the draft TAR and the reports of the Co-Optima project as well.

It is not as if the agencies did not consider fuels in the TAR since fuel related issues are considered for potential longer-term powertrain technologies. The agencies have devoted an entire chapter of the TAR to “Assessment of Alternative Fuel Infrastructure” including a whole section (9.3) on hydrogen fuel infrastructure to support fuel cell vehicles.[27] Although fuel cells are not envisioned to be commercially viable in the timeframe being considered in the TAR, the agencies state that *“The success of the FCEV* [fuel cell electric vehicle] *as a commercial product will rely on the development of a fueling infrastructure network that can provide that hydrogen with a retail experience meeting the expectations of today’s gasoline-fueled vehicle drivers*.” Certainly the same could be said of High Octane Low Carbon fuels and the higher compression engines that this fuel could make commercially successful.

What are we asking the agencies to do?

If the draft Technical Assessment Report is truly to reflect all of the “*relevant new issues that may present themselves,”* then a discussion of universally available, lower carbon, reasonably priced, higher octane fuel should be included. Indeed, given the volume of research in the technical literature in the past several years devoted to the opportunity of increased engine efficiency with high compression ratio engines and high octane fuel, the agencies cannot ignore high octane fuels in its assessment of technologies to meet the fuel economy and greenhouse gas standards. Given also the environmental and economic benefits that a lower carbon ethanol blend fuel can provide, that discussion should include a detailed description of the steps that the agencies could take to make this fuel a reality. Specifically, we urge the agencies to:

- Keep the TAR in draft form until the Co-Optima program has made its recommendations on a candidate fuel. Since the draft TAR was not even required to be issued until November 15, 2017, the agencies should continue to keep the contents of the TAR fluid until all the relevant data are available, including the comprehensive testing being done by the national laboratories as part of the Co-Optima program.
- Keep the dockets open to allow on-going research to be added as results are finalized. For instance, there is interest in upgrading the functionality of the OMEGA model used by AIR in the attached study to include the ALPHA model developed by EPA to more accurately characterize the cost benefits of high octane low carbon fuel and estimate the cost per ton of CO2 emissions achieved through the use of this new fuel. We would encourage the agencies to have a formal mechanism by which such research could be added to the public record. Also, studies quantifying the importance of work vehicles to our economy could be completed.

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[26] “No later than November 15, 2017, the Administrator shall issue a draft Technical Assessment Report addressing issues relevant to the standards for the 2022 through 2025 model years,” FR, Vol. 77 No. 199, October 15, 2012 pg. 63161.

[27] Draft Technical Assessment Report, pg. 9-25

- Add a discussion to the TAR of the range of higher octane, lower carbon fuels being considered by the Co-Optima project. Based on the research done on ethanol blend fuels to date, we are confident that a 20% - 30% ethanol blend fuel will be among the finalists. Given the economics and ease of implementation of this fuel, it appears to be the most promising candidate to alter the ever-escalating cost of more stringent greenhouse gas emission standards.

At some point in the mid-term review process, consider the regulatory changes needed to enable higher efficiency engines and lower carbon fuels. The obvious first step is to define the process to establish a minimum octane requirement for vehicle fuels. The automotive industry has made its case for the necessity of such a fuel standard. If additional ethanol is blended into today's regular E10, this fuel can be produced whenever it is needed without increasing the cost of vehicle fuel. Then, to help enable the transition to a new fuel, automakers will need changes in the certification regulations that (a) make the optimum low carbon fuel (e.g., a 98 RON 25% ethanol blend fuel) as an available certification fuel, (b) reflect the unique properties of low carbon certification fuels and (c) retain and expand credits for manufacturers that offer vehicles that promote greater low carbon fuel use.

Conclusion

The cost to comply with the 2022 – 2025 greenhouse gas emission and fuel economy standards is increasing exponentially with the technologies under consideration in the TAR. Of the vehicles on the road today, only 3% can meet the 2025 standards, and none of those 3% use conventional powertrains. This is a serious problem not only to the standards under review but to the entire national program. Fortunately, there is a technology package that can alter the cost curve for these standards. The combination of universally high octane fuel made with ethanol and the high compression engines that fuel enables can dramatically reduce the cost of compliance with these and future standards.

Based on the work of Air Improvement Resource shown in Attachment 1, it is reasonable to assume that if EPA had included high octane, low carbon fuels and high compression engines optimized to run on that fuel in their OMEGA model, the result would be a cost savings to the consumer in 2025 of at least \$400 on the average vehicle and nearly \$900 on popular models like crossover SUVs with three row seating.

Cost savings of this magnitude would benefit all consumers, but especially those most dependent upon the individual on-demand mobility that cars and trucks provide: specifically, low income households and small businesses that need cost effective reliable work trucks.

The potential to raise the octane floor of the fuel used in the US without increasing the cost per gallon over regular grade E10 is an opportunity that deserves consideration immediately. This fuel could enable more efficient, higher compression engines that not only reduce greenhouse gas emissions and reduce petroleum consumption but also provide as good or better fuel economy than vehicles designed to run on current E10. This seems clearly to be a topic that should be an integral part of the mid-term review process.

Attachment 1
Evaluation of Costs of EPA's 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines
AIR, Inc.[1]
September 22, 2016

1.0 Introduction

In August of 2012, EPA released a final rule setting greenhouse gas (GHG) standards for cars, light trucks, and SUVs for model years 2017-2025. [2] The final standards for model year 2025 were projected to result in a fleetwide CO_2 tailpipe emissions of 163 g/mi, if achieved exclusively through fuel economy improvements. The final standards were based on vehicle footprints, so that all vehicles would achieve GHG emission reductions, regardless of size. EPA expected that improvements would come from advances in engines and transmissions, weight reduction, improved aerodynamics, advances in internal combustion engines, along with increases in hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs). New 2025 model year vehicles (cars and trucks combined) were estimated to cost $1,800 more than 2016 model year vehicles.

Since the standards were finalized with a long lead-time before they took effect, EPA committed to releasing a Technical Assessment Report (TAR), in 2016 to reassess the feasibility of the 2022-2025 model year standards. This report was released in July of 2016. The report generally reaffirmed the feasibility of the original GHG standards.

One key, inexpensive technology that could improve vehicle fuel economy, which was not evaluated by the either the Final Rule or TAR, is an increase in engine compression ratio (CR) that is enabled by a high-octane fuel. Current production engine compression ratios are limited by the octane of gasoline in the U.S. If octane is increased, engine compression ratios can increase, increasing engine efficiency and reducing GHG emissions. So called premium fuel with higher octane content does enable higher compression ratios, but the price difference between premium and regular fuel, along with the concern that vehicles designed for premium would most often be operated on regular because of the price difference in the fuels, effectively limits the amount that automakers can increase compression ratios in the U.S. A high-octane mid-level ethanol blend, however, is likely to be very price-competitive with current regular fuel. If such a fuel were widely available at a competitive cost to regular, auto manufacturers would be likely to employ increased compression ratios to reduce GHG emissions. There is much research going on in this area related to how much engine compression ratios could be

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[1] This study was made possible through a research grant from the Minnesota Corn Research and Promotion Council.

[2] EPA and NHTSA Set Standards to Reduce Greenhouse Gases and Improve Fuel Economy for Model Years 2017-2025 Cars and Light Trucks, Regulatory Announcement, USEPA, OTAQ, EPA-420-F-12-051, August 2012.

increased with mid-level ethanol blends, such as E25 or E30. EPA has also indicated that high-octane fuels could be examined to improve GHG emissions post-2025.[3]

The attractiveness of a high-octane mid-level ethanol blend goes beyond just meeting the GHG standards. The Renewable Fuel Standard (RFS) reduces up-stream GHG emissions reductions from future fuels by requiring increasing amounts of low-GHG fuels. The increase in these required low GHG fuels, however, has declined from the levels originally intended because development of cellulosic biofuel is taking somewhat longer than originally anticipated, and because gasoline marketers have not developed refueling infrastructure for E85 due to slow sales of E85. The slow sales of E85, however, are a function of how E85 has been priced relative to its energy content. The availability of a high octane mid level blend for vehicles purposely designed for this fuel, would spur additional advances in cellulosic biofuel, thereby increasing the benefits of the RFS.

To attempt to fill the gap in the Final Rule and TAR analysis on high-octane fuels, this study evaluates the possible implementation of higher compression ratio (HCR) engines using high-octane low carbon (HOLCF) fuel in the 2022-2025 model years, and the impacts on the costs of EPA's GHG standards. In this study, we assume the same tailpipe GHG standards as EPA's final rule, so the environmental benefits of this HCR/HOLCF strategy *exceed* the benefits of the current TAR, because under HCR/HOLCF, the tailpipe benefits are the same as the TAR, while the upstream benefits of the RFS are greater than currently estimated by EPA.

In this study, we evaluate the impacts of the widespread availability of a 98-RON E25 fuel.[4] We mainly focus on the impacts on the TAR-estimated costs, and for simplicity ignore the potential increases in RFS benefits, which are significant. There are three general parts to the analysis. In the first part, we estimate how much of an increase in CR is possible with 98-RON E25 based on existing research, and the effects on tailpipe GHG emissions. In the second part, we estimate the costs of compression ratio increases, and also 98-RON E25 fuel costs, relative to regular E10. In the third part, we implement high compression ratio engines and the total engine plus fuel costs into EPA's modeling system, and compare program costs and technology penetrations before and after this implementation.

We do not evaluate the impacts of a premium fuel on compression ratios and overall program costs. The main reason for this is cost – the current price differential of premium over regular in the US is about $0.26/gallon. Using EPA's mileage accumulation rates for passenger cars, an assumed fuel economy of 45 mpg, and a 7% discount rate, the net present value of the fuel costs is $860, close to the average new vehicle cost in the TAR. While the use of premium fuel to improve compression ratio would reduce technology costs to meet the GHG standards, with the historical and expected price differential

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[3] Technical Assessment Report, pg. 5-42, "this program [Co-Optima] has the potential to provide meaningful data and ideas for GHG and fuel consumption reductions in the light-duty vehicle fleet for 2026 and beyond".

[4] The selection of this level of ethanol is for the purposes of this study. If automakers chose to certify on a different level of ethanol, the benefits of E25 in this study could be scaled.

between regular and premium, it is unlikely that premium would be used extensively by vehicle owners, unless regular fuel were eliminated at service stations.

The study is organized into the following sections:

Section 2 – Effect of Increased Compression Ratio on GHG Emissions
Section 3 – Compression Ratio Costs and Fuel Costs
Section 4 - Incorporating HCR/HOLCF into the EPA OMEGA Model
Section 5 – Discussion

2.0 Effect of Increased Compression Ratio on GHG Emissions

There have been a number of studies over the past several years examining the effect of ethanol on increasing octane, and the effect of octane on increasing compression ratios and engine efficiency. This section reviews several recent studies, and develops an estimate of the reduction in tailpipe GHG emissions that are possible with a high-octane ethanol fuel like 98-RON E25.

2.1 SAE 2013-01-1321

In a 2013 study by Ford Motor Company, a 2013 production 3.5L direct injection turbocharged V6 engine was engine dynamometer tested comparing the standard 10.0:1 compression ratio with 87 AKI E10 commercial fuel with 11.9:1 compression ratio with 96 RON E20 and 101 RON E30.[5] The E20 and E30 fuels were prepared by splash blending denatured ethanol into the E10 base fuel (fuel properties are shown in Table 1). The engine dynamometer testing simulated a light duty pickup truck operating on the EPA city and highway and US06 driving schedules. No engine calibration or hardware changes were made in addition to piston changes to vary compression ratio.

Compared to the E10 standard configuration tests, the E20 fuel with high compression ratio demonstrated 5% reduction in CO_2 emissions on all driving schedules with similar volumetric fuel economy (mpg) results. E30 fuel and high compression ratio showed 5% reduction in CO_2 on the city and highway schedules and 7.5% reduction on the high speed and load US06 schedule, while fuel economy was 3% lower on the city and highway schedules and about equal on US06.

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[5] Leone, T., Anderson, J. et al., Fuel Economy and CO2 Emissions of Ethanol-Gasoline Blends in a Turbocharged DI Engine, SAE 2013-01-1321, April 8, 2013.

Table 1. Test Fuel Properties – SAE 2013-01-1321			
Fuel	E10	E20	E30
Ethanol (%v)	10.2	20.4	31.5
NHV (MJ/kg)	41.5	39.7	37.7
HoV (MJ/kg)	0.41	0.48	0.55
Specific Gravity	0.743	0.749	0.755
RON	90.8	96.2	100.7
MON	84.1	86.1	87.9
AKI	87.4	91.1	94.3

Based on brake mean effective pressure (BMEP) data, the 96-RON E20 enabled a 1.9 increase in compression ratio and increased thermal efficiency without reaching the engine knock limit due to higher RON and the increased charge cooling and increased sensitivity of the higher ethanol content. The data indicated that a higher compression ratio could have been tolerated with E30, perhaps demonstrating additional improvements in efficiency, CO_2 and fuel economy, but that condition was not tested.

Although little data existed in the literature, an approximately 4% to 5% increase in engine efficiency was measured as a result of increasing the compression ratio by 1.9 at part load conditions most important for typical drive cycles. Notably, this study demonstrates that the loss in energy content of E20 compared to E10 was more than offset by the increase in compression ratio, such that the volumetric fuel economy (MPG) and driving range were similar to the baseline condition.

2.2 SAE 2013-01-1634

In another 2013 study by Ford and AVL Powertrain Engineering, a 5.0L direct injection turbocharged V8 engine was tested on an engine dynamometer at part load conditions on E0 gasoline and 100% ethanol (as a substitute for E85) to compare and understand ethanol related engine efficiency improvements reported in previous studies.[6] Properties of the E0 and E100 test fuels are shown in Table 2 below, with E85 also shown for comparison. Single cylinder engine modeling was also used. An approximately 4% improvement in Brake Thermal Efficiency was measured. Major contributors were cooler exhaust gas due to charge cooling related to the higher heat of vaporization of ethanol and lower adiabatic flame temperature. An approximately 7% lower CO_2 emissions were measured, with 4% of the reduction due to improved thermal efficiency and 3% due to the higher hydrogen to carbon ratio (lower carbon content) of ethanol. For other ethanol-gasoline blends, the study indicated that the fundamental thermal efficiency and CO_2 emissions benefits would scale approximately linearly with the molar fraction of ethanol in the blend. These benefits are in addition to opportunities for improved efficiency, which are available due to the greatly improved knock resistance of ethanol-gasoline blends. The study helped to explain the fuel economy and CO_2 implications of increased

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[6] Jung, H., Shelby, M., Stein, R. et al., Effect of Ethanol on Part Load Thermal Efficiency and CO2 Emissions of SI Engines, SAE 2013-01-1634, April 8, 2013.

ethanol content in ethanol-gasoline blend fuels, and its conclusions are expected to be generally applicable to automotive engines with minor variations due engine and fuel system design.

Table 2. Test Fuel Properties – SAE 2013-01-1634			
Fuel	Gasoline	E85	E100
Ethanol (%v)	0	82.7	100
RON	90.7	109	109
MON	83.4	90	90
H/C (mole)	1.83	2.72	3.0
NHV (MJ/kg fuel)	43.4	29.2	26.9
HoV (kJ/kg fuel)	350	850	920
Density (kg/L)	0.748	0.785	0.796

2.3 SAE 2014-01-1228

A more recent Ford and AVL Powertrain engine dynamometer study tested a 3.5L direct injected turbocharged V6 engine[7] with similar fuels and engine compression ratios to the 2013 study referenced above. Compared to the 2013 study, a 13.0:1 compression ratio (CR) was added to the 10.0:1 standard and 11.9:1 ratios. As in the previous study, the engine dynamometer testing simulated a light duty pickup truck. Also, several octane "matched blend" fuels were added to the E10 91 RON base fuel, E20 96 RON and E30 101 RON splash blended fuels from the previous study. For the matched blend fuels, hydrocarbon properties were adjusted in the E20 and E30 fuels to maintain constant 91 RON and MON. Two additional fuels were tested, an E85 108 RON and E10 98 RON (also called E10 premium). As predicted in the previous study, the 101 RON E30 fuel enabled the 13:1 CR with better knock performance than the E10 91 RON base fuel and standard 10:1 CR. No knock benefit was exhibited in the 91 RON E20 and E30 matched blend fuels compared to E10 91 RON.

Table 3. Properties of Splash Blended Test Fuels in SAE 2014-01-1228								
	Splash Blends			Match Blends				
Fuel	E10-91RON	E20-96RON	E30-101RON	E10-91RON	E20-91RON	E30-91RON	E10-98RON	E85-108RON
Ethanol (%v)	10	20.4	31.5	10	20.5	29.5	9.8	84.3
RON	90.8	96.2	100.7	91.8	90.6	90.7	99.0	~108
MON	84.1	86.1	87.9	84.1	83.2	82.7	91.4	~90
H/C (mole)	2.00	2.08	2.18	2.11	2.11	2.20	2.18	2.89
NHV (MJ/kg)	41.5	39.7	37.7	42.0	40.1	38.6	42.5	29.0
HoV (MJ/kg)	0.41	0.48	0.55	0.41	0.48	0.54	0.41	0.86
Specific Gravity	0.743	0.749	0.755	0.735	0.749	0.760	0.725	0.777

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[7] Leone, T., Anderson, J., Stein R. et al., Effects of Fuel Octane Rating and Ethanol Content on Knock, Fuel Economy, and CO_2 for a Turbocharged DI Engine, SAE 2014-01-1228, April 1, 2014.

Compared to the E20 96 RON fuel, the E10 98 RON (or E10 premium) fuel enabled the 11.9 CR with similar knock behavior. Both fuels would be expected to have similar tank-to-wheels CO_2 emission while the E20 96 RON would be expected to have an advantage in well-to-tank and overall lifecycle CO_2. The E10 premium fuel would have about 3.6% better volumetric fuel economy due to higher energy content and a slightly higher knock limit near MBT due to higher RON, while the E20 96 RON showed an advantage in knock behavior at full load BMEP.

CO_2 emissions were substantially reduced with the E20 96 RON and E30 101 RON fuels compared to the E10 91 RON base fuel.

Table 4. Reduction in CO_2 Emissions

Cycle	96-RON E20 with 11.9 CR	98-RON E30 with 13.0 CR
EPA City/Highway	4.8-5.1%	6.0%
US06	4.9-5.7%	9.1%

The matched blend fuels showed only modest (less than 1%) CO2 reductions similar to a Flexible Fuel Vehicle that is optimized for 91 RON fuel. While the E20 96 RON fuel had about 4% less energy content than the E10 91 RON base fuel, the efficiency benefit at 11.9 CR more than offset the lower energy content such that volumetric fuel economy in MPG and driving range were essentially equivalent. For the E30 101 RON fuel and 13.0 CR, the efficiency benefit mostly offset the lower energy content such that MPG was reduced about 2% for the EPA city/highway schedules and improved by 1% for the US06 test.

2.4 2015 National Academy of Sciences (NAS) Study[8]

The NAS study, released in 2015, reviewed the technologies that would be used to meet EPA and NHTSA’s 2017-2025 model year standards, and the agencies’ modeling efforts. The report made a number of recommendations to the agencies to consider for the mid-term TAR.

The NAS report did review several fuel consumption reduction technologies that were not considered in the final 2017-2025 rule. One of the technologies evaluated was a “high compression ratio with high octane gasoline”.

The NAS concluded that:

> At part load, up to 3 percent reduction in fuel consumption for naturally aspirated engines might be realized if compression ratio is increased from today’s typical level of 10:1 to approximately 12:1, which is approximately a 1.5 percent reduction in fuel consumption per 1.0 compression ratio increase.

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[8] “Cost, Effectiveness and Deployment of Fuel Economy Technologies for Light-Duty Vehicles”, National Academy of Sciences, Table S.2, ISBN 978-0-309-37388-3, 2015.

The NAS further estimated an incremental direct manufacturing cost for strengthened pistons and reduced engine tolerances of $50-$100 for a compression ratio increase on regular fuel (no octane increase), and $75-$150 to implement increased compression ratios on high octane regular fuel. The variation in cost is based on engine/car size. NAS did not estimate the cost to increase compression ratio on a high-octane mid-level ethanol blend. Our discussions with auto manufacturers have indicated they think there is very little, and perhaps no cost to increase compression ratio for a mid-level ethanol blend, and that this is a very attractive option to reduce GHG emissions.

2.5 2015 E, S&T Study by Leone, Anderson, Davis, Iqbal, Reese, Shelby, and Studzinski[9]

This 2015 literature review covered a number of very relevant topics related to the driving forces for evaluating engine, vehicle, and fuel changes. In particular, the paper points out that increased fuel economy requirements are leading to engine design changes such as increased turbocharging, cylinder deactivation, downsizing and down-speeding, and all of these changes are leading to increased engine operation at higher loads, where engines are knock-limited (in other words, further trends in these directions cannot continue unless the knock-limited region is reduced). The paper further evaluates recent developments in measuring and characterizing octane measurements and their effect on engine knock resistance.

An empirical expression was developed that allows the estimation of expected vehicle efficiency, volumetric fuel economy, and CO2 emission benefits for future vehicles through higher compression ratios for different assumptions on fuel properties and engine types. The method utilized data from a 3.5 L GTDI engine tested with CRs of 10:1, 11.9:1, and 13:1 run on an engine dynamometer. The method describes 3 types of efficiency gains from higher octane ethanol fuels – an efficiency improvement due to the use of higher compression ratios, an efficiency gain due to engine downsizing, and an efficiency gain from ethanol itself, which is related to the chemical properties of ethanol, including its higher heat of vaporization.

Table 5 shows these estimated efficiency gains, tailpipe CO2 reductions, and fuel economy changes for a 96-RON E20 and a 101-RON E30, relative to a 91-RON E10. For the 96-RON E20 fuel, the efficiency gain from compression ratio is 3.48%, with 0.5% from higher ethanol content and 0.35% from downsizing. These values are higher for a 101-RON E30 fuel. The estimated CO2 reduction for the E20 fuel is -4.5% and for E30 is 7%. There is little change in volumetric fuel economy for either fuel, as the efficiency gain basically counteracts the reduction in ethanol energy content.

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[9] "The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency, Leone, Anderson, Davis, Iqbal, Reese, Shelby, Studzinski, Environmental Science and Technology, 2015, 49, 10778-10789.

Table 5. Estimated Benefits of Higher Octane Ethanol Fuels Estimated in Paper (Relative to 91-RON E10)		
Parameter	96-RON E20	101-RON E30
Efficiency gain from higher compression ratio	3.48%	5.35%
Efficiency gain from higher ethanol content	0.51%	1.07%
Efficiency gain from downsizing	0.35%	0.54%
Total efficiency gain	4.4%	7.0%
Tailpipe CO2 change	-4.5%	-7.0%
Fuel economy change	0.6%	-1.2%

2.6 July 2016 Study by Oak Ridge National Laboratory (ORNL)

Considerable engine and vehicle based research has been performed in the past several years at the US Department of Energy Oak Ridge National Laboratory (ORNL) to determine the potential efficiency and performance benefits of high octane mid-level ethanol fuel blends. A recent report documented the results of a dedicated vehicle test program using a current production 2.0L direct injection turbocharged Cadillac ATS, with driveline modifications to “downspeed” the engine by about 20% as one of many strategies to meet new fuel economy and greenhouse gas emission requirements. [10]

Engine “downsizing” was also simulated by testing the vehicle at 4,750 pound test weight common to a mid-size sport utility vehicle Test fuels ranged from 87 AKI base fuel to 101 RON, and E0 to E30. The production 9.5:1 CR was used for this phase of the ORNL testing. Engine efficiency as measured by gasoline equivalent miles per gallon[11] was improved by about 10% with the E30 101 RON fuel compared to the baseline vehicle condition and E10 87 AKI (91 RON) fuel on the US06 and the EPA highway fuel economy schedules.

As a continuation of the ORNL high octane mid-level ethanol blend research, a vehicle based chassis dynamometer study is currently underway at ORNL sponsored by the National Corn Growers Association (NCGA) to evaluate CO2 emissions performance of a modified 2.0L direction injection turbocharged Cadillac ATS with E10 87 AKI regular grade gasoline and splash blended E25 98 RON fuel. Vehicle modifications include replacement pistons to increase CR from production 9.5:1 to 10.5:1 and driveline modifications to “downspeed” the engine by about 20%. Test conditions will include 4,750- pound test weight to simulate a “downsized” engine installation in a light duty mid-sized utility vehicle. Based on several previously referenced research studies and numerous other studies in the public literature comparing current production engines and

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[10] West B. ORNL, McCormick, R. NREL, Wang M. ANL et al., Summary of High-Octane, Mid-Level Ethanol Blends Study, ORNL/TM-2016/42, July 2016.

[11] Fuel economy in MPG normalized to 97 RON E0 (93 AKI) fuel based on lower (volumetric) heating value.

vehicles to increased CR with high-octane mid-level ethanol blend fuels, a demonstration of substantial CO_2 emission benefits is expected. Test results from the study are expected near the end of the 2016 calendar year.

2.7 GHG Emission Reduction Used for High Compression in This Study

Most of the previous studies indicated a GHG emissions reduction in 4-8% range for E20-E30 fuels with RONs of 96-101. In this study, we will base our estimate of the GHG emissions reduction on the 2015 E, S&T paper, which developed comprehensive impacts for a 96-RON E20 and a 101-RON E30. The tailpipe GHG emissions change for a 98-RON E25 would be one-half of the reductions of these two fuels, or 5.75%. We will round this to 6%. In addition to 6%, we will estimate the impacts of reductions of 4% and 8%

3.0 Compression Ratio Costs and Fuel Costs

3.1 Compression Ratio Costs

The NAS study covered in the previous section estimated a $75-$150 cost for increased compression ratios for engines using higher- octane regular fuel (without ethanol). This is for improved pistons and rings and reduced tolerances. We also contacted automakers, and their impression was that costs of increased compression ratio would be near zero, especially if it were accomplished during normal engine re-design cycles. [12]

Table 6 shows costs estimated by EPA for various technologies for conventional vehicles. The last row shows the estimated effectiveness and cost of increased compression ratios. Increasing compression ratios on conventional engines appears to be one of the most effective, and least costly, alternatives to increasing engine efficiency.

Table 6. Comparison of Increased CR with Other Technologies

Technology	Effectiveness (%) – EPA	Total Cost ($) – EPA
Improved Lubricants	0.5-0.8	3
Engine Friction Reduction 1	2.0-2.7	46-123
Engine Friction Reduction 2	3.4-4.8	101-254
Cylinder Deactivation	3.9-5.3	130-230
Intake Cam Phasing	2.1-2.7	49-97
Dual Cam Phasing	4.1-5.5	100-214
Discrete Variable Valve Lift	4.1-5.6	171-353
Continuous Variable Valve Lift	5.1-7.0	256-512
Increased Compression Ratio	6-7	75-150 (NAS)

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[12] During a Co-OPTIMA Stakeholder "Listening Day" held June 16-17, 2015, several auto makers indicated that "if 100 RON was available today, manufacture of compatible engines would be a given." "Co-Optima Stakeholder Listening Day Summary Report", US Department of Energy, National Renewable Energy Laboratory, June 2015.

For the purposes of this analysis, we will assume a $100 total cost for increasing compression ratios for engines for a 98 RON E25 fuel.

3.2 Fuel Costs - Forecasting Fuel Prices Through 2040

The current version of EPA's OMEGA model uses the Energy Information Administration (EIA) 2015 Annual Energy Outlook (AEO 2015) future forecast of retail gasoline to estimate the fuel savings (in 2013 dollars) that consumers realize as a result of more stringent fuel economy standards. In order to add a new technology of high compression spark ignition engines and high-octane fuels to the OMEGA model, it is necessary to use the information in AEO 2015[13] to establish forecasts out to 2040 for high-octane regular gasoline with its octane boosted to premium gasoline levels using additional ethanol.

3.2.1 Methodology

The two relevant values forecast in AEO 2015 are the retail price of gasoline, and the wholesale price of ethanol. For the retail price of gasoline, this is the forecast average price for all blends of gasoline (except E85) and includes all local, state and federal taxes ($0.44 a gallon) and product markups ($0.15). The wholesale price of fuel ethanol is forecast out to 2040 assuming that the volumes of the RFS are met with the following exception:

> The RFS is included in AEO2014, however it is assumed that the schedule for cellulosic biofuel is adjusted downward consistent with waiver provisions contained in the law.

In order to forecast the future costs of mid-level blend fuel, the following steps need to occur. The first is that the wholesale price of regular grade (87 AKI octane) gasoline needs to be determined based upon AEO prices of "Retail Gasoline." This involves unbundling two effects: the removal of taxes and markups from the retail price, and the price impact of premium grade fuel and other ethanol blends on the retail price. Ultimately, it was concluded that these factors could not be unbundled using data from EIA alone, so the average of the weekly price differential between regular and premium blendstock from May 5, 2014 to August 22, 2016 published by Oil Price Information Service was used. This constant ($0.26 a gallon) is used to both convert the AEO 2015 price for all grades of retail gasoline (primarily regular grade and plus premium grade E10) into regular grade E10. The retail price for gasoline shown in AEO 2015 marks up the wholesale price for federal, state and local taxes and retail mark-up. These total $0.59 a gallon.[14]

The second step is that the price of E10 84 AKI gasoline blendstock needs to be determined. With the wholesale price of both E10 (10% ethanol and 90% gasoline blendstock) and ethanol known, it is a simple calculation to determine the implied price

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[13] The prices for retail gasoline and wholesale ethanol are shown in AEO 2015 for select years only. The year-by-year values were provided by EIA directly. The assumptions used in generating these numbers were found in the document "Assumptions to the Annual Energy Outlook", EIA, September, 2015.

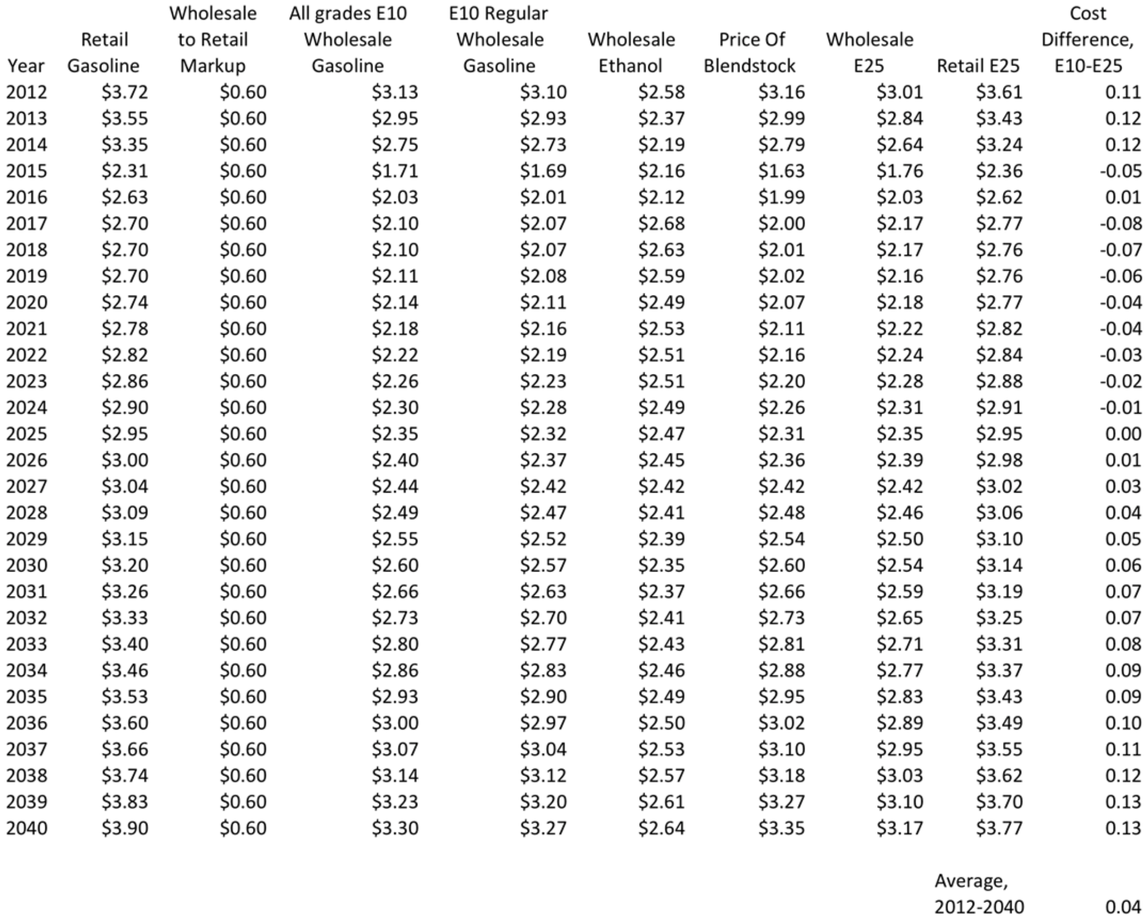
[14] "Assumptions to the Annual Energy Outlook," Energy Information Administration, September, 2015.

of the blendstock. The formula is $P_B = (P_{E10} - 0.1 X P_E) / 0.9$ where P_B is the price per gallon of the blendstock, P_{E10} is the price per gallon of E10 and P_E is the price per gallon of ethanol.

Once the price of the 84 AKI gasoline blendstock is known, the wholesale cost of a 25% ethanol 75% gasoline blend can be determined using the formula $P_{E25} = (0.25 X P_E) + (0.75 X P_B)$ where P_{E25} is the wholesale price per gallon of E25. Adding back in the $0.59 per gallon wholesale to retail constant provides the retail price for E25.

Results of this analysis are shown in Table 7.

Table 7. EIA Price Analysis if E25 versus E10



Year	Retail Gasoline	Wholesale to Retail Markup	All grades E10 Wholesale Gasoline	E10 Regular Wholesale Gasoline	Wholesale Ethanol	Price Of Blendstock	Wholesale E25	Retail E25	Cost Difference, E10-E25
2012	$3.72	$0.60	$3.13	$3.10	$2.58	$3.16	$3.01	$3.61	0.11
2013	$3.55	$0.60	$2.95	$2.93	$2.37	$2.99	$2.84	$3.43	0.12
2014	$3.35	$0.60	$2.75	$2.73	$2.19	$2.79	$2.64	$3.24	0.12
2015	$2.31	$0.60	$1.71	$1.69	$2.16	$1.63	$1.76	$2.36	-0.05
2016	$2.63	$0.60	$2.03	$2.01	$2.12	$1.99	$2.03	$2.62	0.01
2017	$2.70	$0.60	$2.10	$2.07	$2.68	$2.00	$2.17	$2.77	-0.08
2018	$2.70	$0.60	$2.10	$2.07	$2.63	$2.01	$2.17	$2.76	-0.07
2019	$2.70	$0.60	$2.11	$2.08	$2.59	$2.02	$2.16	$2.76	-0.06
2020	$2.74	$0.60	$2.14	$2.11	$2.49	$2.07	$2.18	$2.77	-0.04
2021	$2.78	$0.60	$2.18	$2.16	$2.53	$2.11	$2.22	$2.82	-0.04
2022	$2.82	$0.60	$2.22	$2.19	$2.51	$2.16	$2.24	$2.84	-0.03
2023	$2.86	$0.60	$2.26	$2.23	$2.51	$2.20	$2.28	$2.88	-0.02
2024	$2.90	$0.60	$2.30	$2.28	$2.49	$2.26	$2.31	$2.91	-0.01
2025	$2.95	$0.60	$2.35	$2.32	$2.47	$2.31	$2.35	$2.95	0.00
2026	$3.00	$0.60	$2.40	$2.37	$2.45	$2.36	$2.39	$2.98	0.01
2027	$3.04	$0.60	$2.44	$2.42	$2.42	$2.42	$2.42	$3.02	0.03
2028	$3.09	$0.60	$2.49	$2.47	$2.41	$2.48	$2.46	$3.06	0.04
2029	$3.15	$0.60	$2.55	$2.52	$2.39	$2.54	$2.50	$3.10	0.05
2030	$3.20	$0.60	$2.60	$2.57	$2.35	$2.60	$2.54	$3.14	0.06
2031	$3.26	$0.60	$2.66	$2.63	$2.37	$2.66	$2.59	$3.19	0.07
2032	$3.33	$0.60	$2.73	$2.70	$2.41	$2.73	$2.65	$3.25	0.07
2033	$3.40	$0.60	$2.80	$2.77	$2.43	$2.81	$2.71	$3.31	0.08
2034	$3.46	$0.60	$2.86	$2.83	$2.46	$2.88	$2.77	$3.37	0.09
2035	$3.53	$0.60	$2.93	$2.90	$2.49	$2.95	$2.83	$3.43	0.09
2036	$3.60	$0.60	$3.00	$2.97	$2.50	$3.02	$2.89	$3.49	0.10
2037	$3.66	$0.60	$3.07	$3.04	$2.53	$3.10	$2.95	$3.55	0.11
2038	$3.74	$0.60	$3.14	$3.12	$2.57	$3.18	$3.03	$3.62	0.12
2039	$3.83	$0.60	$3.23	$3.20	$2.61	$3.27	$3.10	$3.70	0.13
2040	$3.90	$0.60	$3.30	$3.27	$2.64	$3.35	$3.17	$3.77	0.13
								Average, 2012-2040	0.04

Table 6 shows that, generally, over the projection until 2040, E25 is about 4 cents per gallon lower than E10. In the time period of 2012-2016 using historical data, E25 would be 6 cents per gallon lower than E10. If E25 is 4 cents lower than E10 over the lifetime of a 2025 vehicle, assuming a 45 mpg fuel economy, a 7% discount rate, and the OMEGA mileage accumulation rates for a passenger car, the NPV of this credit for E25 is $132.23. At 6 cents per gallon lower, the credit for E25 is worth $198.35.

3.2.2 Factors That Could Impact These Forecasts

These price forecasts were developed to enable the modeling of a scenario in which a minimum octane standard would be established that would enable automakers to increase the compression ratio of spark ignition engines at the least possible cost. Automakers have shown that a mid-level gasoline-ethanol blend with a Research Octane Number (RON) of at least 98 has nearly optimal CO_2 reduction and cost per mile[15] which is comparable to today's premium grade E10 gasoline. A 98 RON fuel can be produced using today's regular grade gasoline blendstock by increasing the 10% ethanol to 25%, or E25. While blends between E20 to E40 have been evaluated, this analysis focuses on E25 as typical of a high-octane low carbon fuel formulation.

In order for automakers to be comfortable in significantly increasing the compression ratio of their engines, however, they would need to be assured that there was no danger of that engine inadvertently operating on lower octane fuel. This would require either foolproof misfueling prevention devices or an end to the sale of low octane fuel. For purposes of this analysis, it is assumed that, like the sale of leaded gasoline in the 1970's, EPA would establish a minimum octane rating of 98 RON and set a date after which low octane fuel could no longer be marketed. Or, smart cars and smart fuel pumps would communicate in such as way that cars requiring E25 would not use anything but E25. In any event, this analysis evaluates a long-term steady state situation where fleet turnover to E25 vehicles is nearly complete.

In this analysis, the AEO 2015 prices were used to create these scenarios. Factors that could impact the values calculated for this study include:

- Changes in fuel volume that could increase or decrease the forecast fuel price. For the scenario where regular low octane E10 is replaced with a high octane regular grade E25, the volume changes involved would be an increase in the demand for ethanol and a decrease in the demand for regular grade gasoline blendstock. In this scenario, the amount of the shift in volumes is relatively minor (15% of regular gasoline blendstock would be replaced with ethanol after the minimum octane standard became mandatory). There is a 15% increase in ethanol volumes from 2012 to 2040 already built into the AEO 2015 numbers and hence these price forecasts. Also, the historical record shows that, between 2007 and 2015, ethanol production increased by 127% while the price of ethanol decreased by 37%. There are a number of reasons to believe this relative price insensitivity would apply to the additional volume of ethanol required to change E10 into E25, including:
    - Research underway at the federal level to develop technologies that would reduce the cost of converting cellulosic feedstock to $3 a gallon gasoline equivalent.

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[15] USCAR data shown in the presentation "The Increasing Importance of Fuel Octane," Tom Leone, Ford Motor Company at the Society of Automotive Engineers Industry/Government Meeting, January 2016.

  - The recent Billion Ton report indicating that there are significant volumes of harvestable biomass.
  - Idle former sugar cane farms in the Western Hemisphere that could easily be brought back into production.

  Consequently, this analysis uses the AEO 2015 price forecasts for ethanol to hold true under either scenario.

- Changes to infrastructure necessary to enable the scenarios. The infrastructure changes to replace E10 regular with high octane E25 regular, however, are not too complex. A 2012 study by Stillwater Associates to evaluate the distribution costs of E30 by calendar year 2017 found that distribution costs would range between 0.2 cents and 0.5 cents per gallon, depending on the method used. [16]

Overall, the forecasted prices for E25 in this study are likely not to be significantly affected by consideration of volume and infrastructure costs.

3.3 Total Costs of Increased Compression Ratio and Lifetime Fuel Credit

As indicated in section 3.1, we are assuming a $100 cost for increasing compression ratio of vehicles. However, the lifetime PV fuel credit (using 7% discount rate) in section 3.2.1 is $132.23. For fuel distribution cost, assuming a 0.4 cent per gallon cost, the lifetime PV cost (assuming 7% discount) is $13.22. The costs and credits approximately balance each other, therefore for the remainder of this analysis we are estimating zero net cost to the consumer.

4.0 Incorporating HCR with HOLC fuel into EPA's OMEGA Model

This section explains how we incorporate HCR/HOLC into EPA's OMEGA model, and how the results compare with EPA's default results. We start by examining EPA's results, then we explain the method used, and finally we show the results of HCR/HOLC versus the EPA defaults.

4.1 EPA's Results

Table 8 shows the draft TAR per vehicle costs to meet the 2025 standards, relative to the 2021 model year standards. For GHGs in model year 2025, the costs range between $894 (ICM case) and $1,017 (RPE). These values are directly from Table ES-2 of the TAR. The values reported for the Primary Case reflect the use of Indirect Cost Multipliers (ICM). The sensitivity case utilizes Retail Price Equivalents (RPE). The CAFÉ values reflect RPE values and include civil penalties estimated to be incurred by some models. For the GHG analysis, average costs range between $894 and $1,017.

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[16] The Cost of Introducing an Intermediate Blend Ethanol Fuel for 2017- and- Later Vehicles, study for Air Improvement Resource, Inc, Stillwater Associates, October 17, 2012.

Table 8. Per Vehicle Average Costs to Meet Model Year 2025 Standards; Draft TAR Analysis Costs are Shown Incremental to the Costs to Meet the Model Year 2021 Standards				
	GHG in Model Year 2025		CAFÉ in Model Year 2028	
	Primary Case	RPE Analysis	Primary Case	ICM Analysis
Car	$707	$789	$1,207	$1,156
Truck	$1,099	$1,267	$1,289	$1,096
Combined	**$894**	**$1,017**	$1,245	$1,128

In the first step of incorporating HCR with HOLC fuel into OMEGA, AIR first replicated EPA’s analysis. With some effort and EPA’s assistance, AIR was able to replicate EPA’s result for the GHG Primary Case in 2025 exactly. Some of the key outputs of this analysis are shown in Table 9.

Table 9. Key Outputs of the 2025 Primary GHG Case (Uses ICMs)	
Item	Value
Vehicle sales	16,419,435
Total cost ($)	$23.4 billion
Average Cost (relative to 2014 model year)	$1,425
Average cost (relative to continuation of 2021 model year standards)	$894
CO_2 Target (g/mi)	198.83
Final CO_2 (g/mi)	197.79

The total cost of the 2025 model year emission standards is 23.4 billion dollars, and the average cost relative to the 2014 model is $1,425. This is higher than the $894 in the Table 8, because Table 8’s costs are relative to the continuation of 2021 standards, where Table 9 costs are relative to the reference vehicle, a 2014 model year vehicle. The 2021 average vehicle cost increment we estimated is $531.01, so $1,425-$531.01 = $893.33. Thus, we have been able to replicate EPA’s analysis. A number of cases were run where we replicated the EPA results exactly.

The aggregated results above are estimated from the OMEGA model, which predicts technologies that will be on all cars and light duty trucks to meet the required tailpipe GHG emission standards. There are 2,819 separate vehicle models for all manufacturers in the OMEGA model. Every vehicle model is associated with a vehicle type, of which there are 19 separate types. OMEGA creates up to 50 likely technology packages, which consist of groups of technologies, for every vehicle type. These 50 groups are actually developed by a separate part of the model called the Lumped Parameter Model (LPM). The OMEGA model basically computes the least cost solution to meeting GHG standards for each manufacturer, utilizing all of its models. There can also be more than one technology in the final solution for each vehicle model. The model applies the most cost-effective technologies first, and then continues to apply technologies across different models until the manufacturer meets its emission standard.

Table 10 shows the technologies that are predicted by the OMEGA model to be present on a 2025 Buick Enclave. OMEGA predicts that several technology packages will be present on 2025 Buick Enclaves, however, in reality this may not be realistic (the detailed technologies present on these Technology packages are shown in Attachment 1). Nonetheless, this is what OMEGA predicts.

Table 10. Technologies on a 2025 Buick Enclave Predicted by OMEGA (Central Case using ICMs)

Tech Pkg	Powertrain Type	Sales fraction	Weighted average cost
9	MHEV-48V	25%	$2,146
10	MHEV-48V	55%	
11	ATK	20%	

MHEV = mild hybrid electric vehicle
ATK = Atkinson cycle engine

4.2 Implementation of HCR/HOLCF

The next step was to incorporate HCR/HOLCF. In the previous section (Section 3), we estimated a primary case GHG benefit for HCR/HOF of 6%. In this analysis, we will estimate the impacts of a 4%, 6%, and 8% benefit. Also in the previous section, we evaluated costs of the high compression ratio technology, the HOLCF fuel, and fuel distribution costs, and concluded that the net costs of these 3 items are zero. So, we are estimating the impacts of 3 benefit cases – 4%, 6%, and 8%.

Our first thought was to introduce HCR in the OMEGA model as a new, single technology. However, this technology would not have been recognized by the model and integrated into the existing technology packages without extensive work, so we had to develop an alternative solution.

Our approach was to (1) classify each technology as a conventional vehicle (CV), hybrid electric vehicle (HEV), Atkinson cycle engine, or battery electric vehicle (BEV), and (2) apply the HCR benefit and costs only to conventional vehicles and Atkinson cycle engines not associated with an HEV, and (3) re-run OMEGA to determine the cost differences. We explain this process using the example of Buick Enclave below, assuming a 6% reduction in emissions for a HCR engine, with zero net cost.

The first eleven technology packages for Vehicle Class 8 (midsize MPV V6) are shown in Table 11. Technology Package 0 is the starting point for every vehicle class. The actual technologies for the first 11 Enclave technology packages are shown in Attachment 1 (there are many more technology packages for Enclave, but we only show the first 11). There is no change in the CO_2 emissions or cost for Technology 0 (the starting point). For Tech Package 1, the original CO2 is 327.3 g/mi. Our assumption is that because of its low cost and attractive effectiveness, high compression ratio would be included on all conventional technology packages from Tech Package 1 and higher. The CO_2 emissions of Tech Package 1 are estimated by multiplying the CO_2 emissions of Tech Package 0 by 6% (21.49 g/mi), and subtracting that value from the original Tech

Package 1 value (327.3-21.49 = 305.81). This process is carried on for all conventional vehicles, because our assumption is that all conventional vehicles would be equipped with high compression ratio engines.

Table 11. Buick Enclave Technology Packages

Tech #	Type	Original (EPA)		6%, $0	
		CO_2	Cost	CO_2	Cost
0	Conv	358.1	$0	358.1	$0
1	Conv	327.3	$333	305.8	$333
2	Conv	306.3	$485	284.8	$485
3	Conv	272.2	$505	250.7	$505
4	Conv	260.7	$700	239.3	$700
5	Conv	241.9	$1,275	220.4	$1,275
6	Conv	252.7	$947	231.2	$947
7	Conv	247.8	$1,269	226.3	$1,269
8	ATK	231.9	$1,770	218.0	$1,770
9	MHEV-48V	229.7	$1,882	229.7	$1,882
10	MHEV-48V	216.7	$2,314	216.7	$2,314
11	ATK	225.0	$2,017	211.5	$2,017

Tech packages 9 and 10 for the Enclave are 48-volt mild hybrids. To be conservative in our analysis, we have applied no compression ratio reduction in emissions for these vehicles, even though they have an internal combustion engine that would probably benefit from a higher compression ratio engine. Tech package 11 includes an Atkinson cycle engine. Atkinson cycle engines in this context are assumed to have higher compression ratios due to intake and exhaust timing changes. Atkinson cycle engines already have higher compression ratios, however, with a higher-octane fuel, there is the possibility that the compression ratio could probably be increased from the compression ratio they would be designed for with 87-octane fuel. Thus, there would probably be an efficiency gain to higher compression ratios for Atkinson engines. Thus, we have modeled Atkinson engines by subtracting the 6% reduction in GHG emissions from the EPA CO_2 emissions for that technology package. [17] Six percent of 225 is 13.5 g/mi, so the CO_2 of Atkinson Enclave with increased compression ratio due to high octane fuel would be 211.5 g/mi.

Note that applying the benefit of HCR in this manner is not diminishing the benefits of the other technology packages. For example, the difference in emissions between Tech Package 1 and Tech Package 2 is 21 g/mi CO_2 in both cases. Also, in automatically applying HCR to all conventional technology packages, we are in a sense “forcing” the model to use HCR for all conventional engines. However, with zero or near zero cost and a 6% benefit, the model would have chosen to do that anyway, even if it had been coded

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[17] Some HEVs utilize Atkinson cycle engines. We have assumed no HCR credit for these engines used in HEVs, only ATK engines used without HEV technology.

as a separate technology. Finally, EPA utilizes a combination of the Lumped Parameter Model and the Alpha model to ensure that it is properly accounting for various synergies between different technologies; i.e., that one cannot just add percent benefits for a selection of different technologies to determine an overall Technology Package percent reduction. We have not put HCR through this fairly rigorous treatment. We have assumed that all of the non-HCR packages have gone through that process, and when we add HCR in, that the benefit is undiminished at 6%. We have also run sensitivity cases at 4% and 8% for the reader to evaluate. While the overall method we have used to model HCR may not be exactly what EPA would do in this circumstance because it does not utilize ALPHA modeling, physical simulations, and the Lumped Parameter Model, we believe the method represents a reasonable first approximation of the effects of higher compression ratios on OMEGA results.

The results of this analysis are shown in Table 12. With higher compression ratio engines included, total costs of the 2025 model year standards are reduced from $23.4 billion to $16.8 billion. Sales[18], CO_2 targets and final CO_2 levels are essentially identical.[19]

Table 12. Impact of HCR on Model Year 2025 Vehicle Costs

Item	Without Higher Compression Ratio	With Higher Compression Ratio
Sales	16,419,435	16,419,435
Total Cost Billion ($)	23.4	16.8
Average per vehicle cost $/vehicle	$1,425	$1,021
CO_2 Target (g/mi)	198.83	198.83
Final CO_2 (g/mi)	197.79	197.75

The results for the Enclave are shown in Table 13. The EPA default shows that 80% of Enclave sales in 2025 would be 48V mild hybrids and 20% would be Atkinson cycle engines, while the case with increased compression ratio shows that 100% of vehicles would be conventional (split 75% in Tech package 5 and 25% in Tech package 7).

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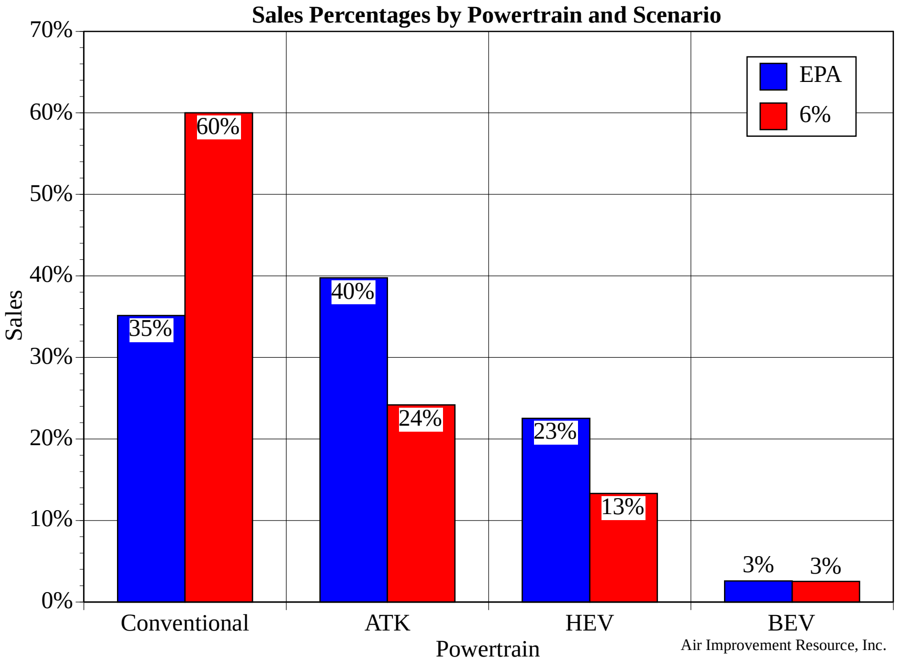
[18] Reducing the cost of new 2025 vehicles by utilizing lower cost technology should result in some sales increase. For purposes of this analysis, however, it is not necessary to model these increases, so each scenario is modeled on the same sales basis.

[19] While final CO2 levels are the same with higher compression ratio engines, the GHG benefits of EPA's GHG standards utilizing high compression ratio engines enabled by high octane low carbon fuel would be greater than EPA's benefits, because of upstream GHG benefits from the low carbon fuel. We have not quantified these upstream benefits in this analysis.

Table 13. Impact of HCR on Buick Enclave Model Year 2025 Technologies				
Run	Tech Pckg	Powertrain Type	Sales	Weighted Average Cost
EPA Default (without higher compression ratio)	9	MHEV-48V	25.00%	$2,146
	10	MHEV-48V	55.00%	
	11	ATK	20.00%	
6%_$0	5	Conv	75.00%	$1,273
	7	Conv	25.00%	

Figure 1 shows the impact of HCR on 2025 model year sales percentages by powertrain. HCR reduces the conversions to Atkinson cycle and HEVs, but appears to have no effect on the percent of battery electric vehicles.

Figure 1



Figures 2-5 further show the impacts of high compression ratio on 2025 model year fleet technology costs, average vehicle technology costs, average vehicle costs by powertrain type, and sales percentages by powertrain type.

While it was necessary to make some simplifying assumptions to utilize the OMEGA model to obtain these results, we are confident that, if EPA had included this technology package in their OMEGA modeling for the mid-term review, they would have observed similar cost savings for the 2025 model year. The 2025 model year is significant for several reasons:

- It is the last model year considered in the TAR.
- It will be the baseline year for future greenhouse gas emission and fuel economy standards.
- It is the first year that the Co-Optima program indicates a new high-octane fuel could reach the market.[20]

It should also be noted that this analysis was performed to predict what EPA would estimate the potential cost-savings of this new technology would be in 2025. Therefore, we have retained the same assumptions regarding costs as EPA has used. Others, however, calculate costs differently. NHTSA, for example, estimates costs using the Retail Price Equivalent Method of mark-up while EPA retains the use of the Indirect Cost Multiplier method. The NHTSA methods result in higher compliance costs than EPA. Therefore, it is quite possible that the actual cost savings will be much greater than the numbers predicted in this study.

Figure 2

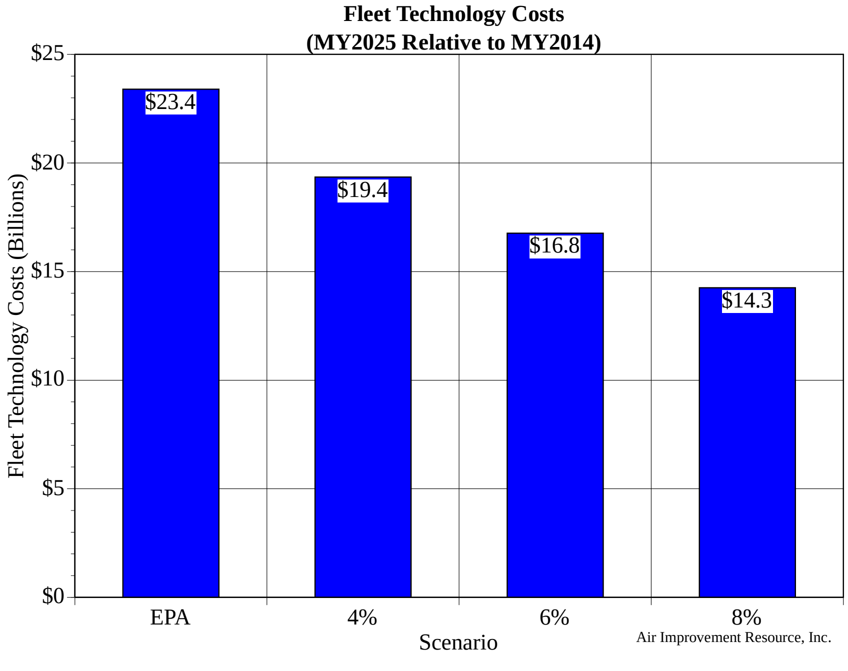


Figure 3

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[20] From the TAR discussion of the Co-Optima program, page 5-42 “Two parallel research tracks focus on: 1) improving near-term efficiency of spark-ignition (SI) engines through the identification of fuel properties and design parameters of existing base engines that maximize performance. The efficiency target represents a 15% fuel economy improvement over state-of-the-art, future light-duty SI engines with a market introduction target of 2025.”

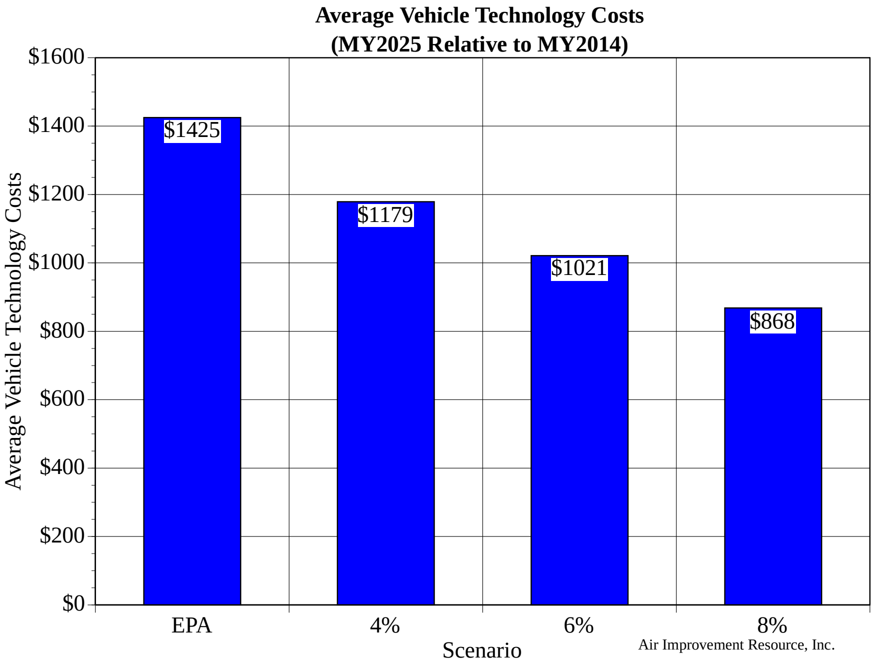


Figure 4

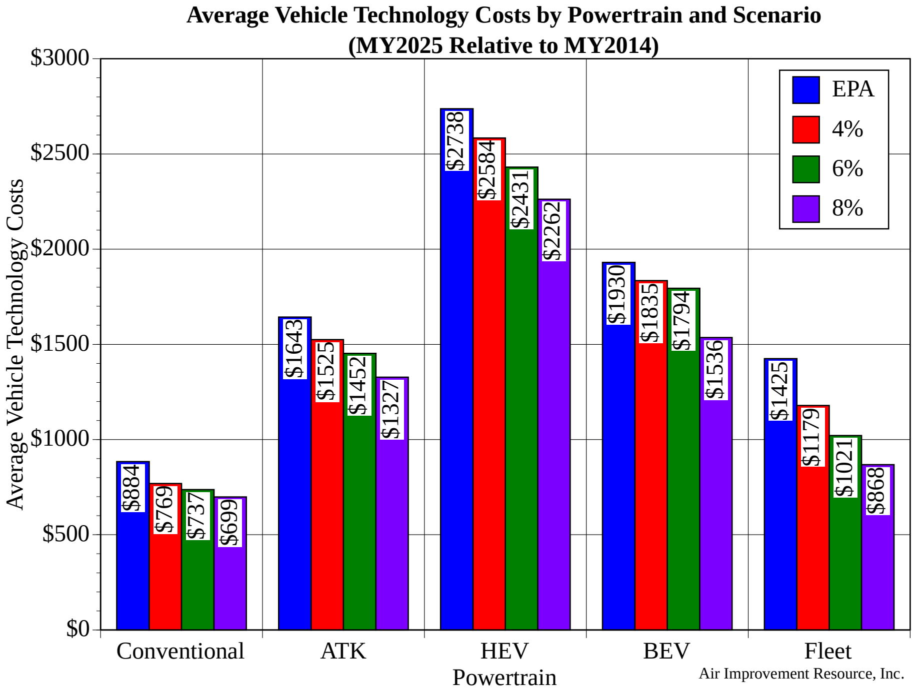
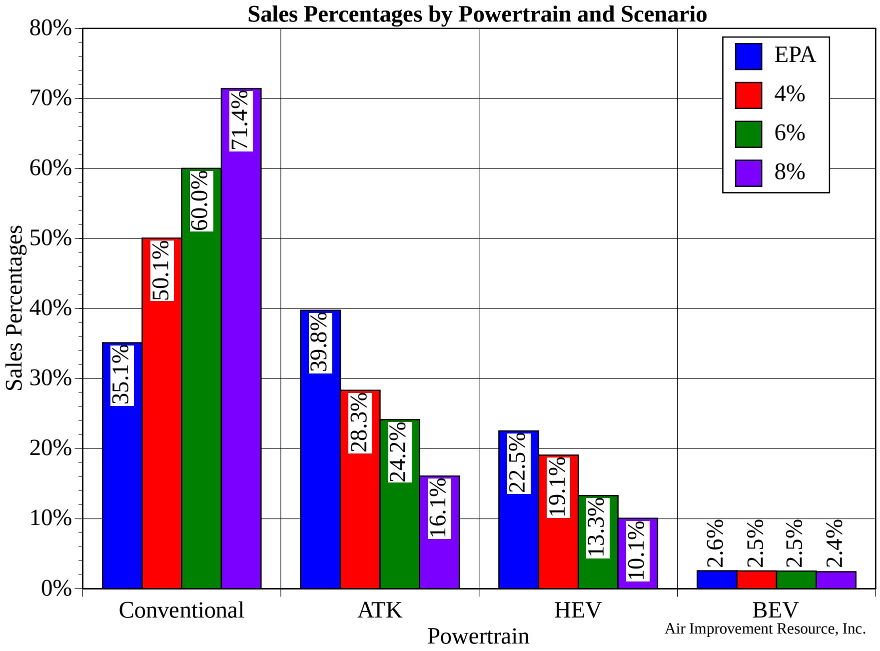


Figure 5



6.0 Discussion

This analysis has shown that if a high octane mid-level blend ethanol fuel such as 98-RON E25 were an option for model year 2022-2025 vehicles meeting EPA's GHG standards, overall program costs would be significantly reduced. There is no doubt that if this fuel were to be made widely available to the public, auto manufacturers would certify vehicles using it.

Major inputs to this conclusion are (1) the magnitude of GHG emission reduction due to increased octane, (2) the cost of higher compression ratio plus the incremental cost (or savings) from the fuel, and (3) how implementing high HCR would affect the benefits of other types of technologies.

We have estimated the tailpipe GHG emission reduction due to higher compression engines for the central case at 6%. This effectiveness is somewhat higher than most other technologies estimated by EPA, but it is not out of line, and in fact could perhaps be considerably higher. There is a significant amount of research currently being done to refine this estimate, and the type of fuel needed to obtain as much engine efficiency improvement as practical. Our cost for the increased compression ratio of $100 also does not appear out of line, as some manufacturers have indicated it could be much less if done as a part of normal engine redesign cycles. Our analysis of fuel costs indicates that the fuel could be provided for slightly less than the current cost of regular. At this point, we are not sure how implementing HCR would affect the benefits of some of the other technologies, but more work will probably be performed on this as well.

Finally, another significant benefit of implementing a high-octane ethanol fuel with high compression ratio engines is that biofuel use would grow more significantly from today's levels, thereby reducing upstream GHG emissions from transportation fuels, growing the GHG benefits of the Renewable Fuel Standard, and reducing US petroleum consumption. Thus, the overall GHG benefits of EPA’s 2022-2025 GHG standards with a high-octane low carbon fuel would be significantly greater than without a high-octane low carbon fuel.

Attachment 1

Detailed Technology Packages for the First 11 Tech Packages for the 2025 Buick Enclave

TP	Aero1	Aero2	ATK2	Deac-V6	DI	EFR1	EFR2	EGR	EPS	I4	IACC1	IACC2	LDB	LRRT1	LRRT2	LUB	MHEV48V	SAX-NA	Stop-Start
0					DI	EFR1										LUB		SAX-NA	
1	Aero1				DI	EFR1			EPS		IACC1		LDB	LRRT1		LUB		SAX-NA	
2	Aero1				DI	EFR1			EPS		IACC1		LDB	LRRT1		LUB		SAX-NA	
3	Aero1				DI		EFR2		EPS	I4	IACC1		LDB		LRRT2			SAX-NA	
4		Aero2			DI		EFR2		EPS	I4		IACC2	LDB		LRRT2			SAX-NA	
5		Aero2			DI		EFR2	EGR	EPS	I4		IACC2	LDB		LRRT2			SAX-NA	
6		Aero2			DI		EFR2		EPS	I4		IACC2	LDB		LRRT2			SAX-NA	
7		Aero2			DI		EFR2		EPS	I4		IACC2	LDB		LRRT2			SAX-NA	Stop-Start
8		Aero2	ATK2	Deac-V6	DI		EFR2	EGR	EPS			IACC2	LDB		LRRT2			SAX-NA	Stop-Start
9		Aero2			DI		EFR2		EPS	I4		IACC2	LDB		LRRT2		MHEV48V	SAX-NA	
10		Aero2			DI		EFR2	EGR	EPS	I4		IACC2	LDB		LRRT2		MHEV48V	SAX-NA	
11		Aero2	ATK2	Deac-V6	DI		EFR2	EGR	EPS			IACC2	LDB		LRRT2			SAX-NA	Stop-Start

TP	TRX11	TRX21	TRX22	TURB18	TURB24	V6	VVLTD-OHC-I4	VVT	WRnet- 1.5	WRnet- 2.5	WRnet- 5.0	WRpen- 0.0	WRpen- 2.5	WRtech- 1.5	WRtech- 5.0
0	TRX11					V6		VVT	WRnet- 1.5			WRpen- 0.0		WRtech- 1.5	
1	TRX11					V6		VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
2		TRX21				V6		VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
3		TRX21		TURB18				VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
4		TRX21		TURB18				VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
5		TRX21			TURB24			VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
6			TRX22	TURB18				VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
7			TRX22	TURB18				VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
8		TRX21				V6		VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0
9			TRX22	TURB18			VVLTD-OHC-I4	VVT		WRnet- 2.5			WRpen- 2.5		WRtech- 5.0
10			TRX22		TURB24			VVT		WRnet- 2.5			WRpen- 2.5		WRtech- 5.0
11			TRX22			V6		VVT			WRnet- 5.0	WRpen- 0.0			WRtech- 5.0

Abbreviation	Description	Abbreviation	Description
Aero1	Aero – passive	SAX-NA	Secondary axle disconnect; Not Applicable
Aero2	Aero – passive with active	Stop-Start	Stop-start without electrification
ATK2	Atkinson-2	TRX11	Transmission – step 1 or current generation
Deac-V6	Cylinder deactivation V6 engine	TRX21	Transmission – step 2 or TRX11 but with additional gear-ratio spread
DI	Gasoline direct injection	TRX22	TRX21 with improved efficiency
EFR1	Engine friction reduction level 1	TURB18	Turbocharging at 18/21 bar
EFR2	Engine friction reduction level 2	TURB24	Turbocharging at 24 bar
EGR	Cooled exhaust gas recirculation	V6	V-shaped 6-cylinder engine
EPS	Electric power steering	VVLTD-OHC-I4	Discrete variable valve lift and timing on an overhead cam I4
I4	Inline 4-cylinder engine	VVT	Variable valve timing
IACC1	Improved accessories level 1	WRnet- 1.5	Weight reduction, net, 1.5%
IACC2	Improved accessories level 2	WRnet- 2.5	Weight reduction, net, 2.5%
LDB	Low drag brakes	WRnet- 5.0	Weight reduction, net, 5.0%
LRRT1	Lower rolling resistance tires level 1	WRpen- 0.0	Weight reduction, penetration, 0.0%
LRRT2	Lower rolling resistance tires level 2	WRpen- 2.5	Weight reduction, penetration, 2.5%
LUB	Engine changes to accommodate low friction lubes	WRtech- 1.5	Weight reduction, technology, 1.5%
MHEV48V	Mild hybrid 48V	WRtech- 5.0	Weight reduction, technology, 5.0%

About the Authors

Mr. Thomas Darlington is President of Air Improvement Resource, a company formed in 1994 specializing in mobile source emission modeling. He is an internationally recognized expert in mobile source emissions modeling. He has evaluated the emission benefits and cost effectiveness of nearly every major on-road and off-road regulation proposed and adopted since 1988 in the U.S. and Canada. He has also reviewed and commented on the all of the emission models developed by the EPA and the California Air Resources Board in the 1990s. He has been called upon to testify on such regulations at EPA workshops and hearings, and at ARB workshops and Board Hearings in Sacramento, California. He has also reviewed EPA's Renewable Fuel Standard (RFS) and California's Low Carbon Fuel Standard (LCFS). He critically reviewed both Agencies' lifecycle analyses of corn ethanol, sorghum ethanol and palm oil biodiesel, including multiple reviews of changing indirect land use emissions. He prepares applications for biofuel companies for the LCFS and the RFS.

Mr. Dennis Kahlbaum is an expert in meteorology, computer programming, statistical and data analysis, graphical presentation, and geographical information systems (GIS). To assist with the requests of AIR's clientele, he has created special versions of the on-highway and off-highway emission and fuel consumption models in use by both the EPA and California Air Resources Board (CARB), including MOVES, MOBILE6, NONROAD, OFFROAD, and M6FCM. He has also executed and modified the GTAP6, GTAP7, FASOM, GREET, CCLUB, and AEZ-EF models to estimate the land use change (LUC) and greenhouse gas (GHG) emissions resulting from the EPA Renewable Fuels Standards (RFS) and CARB Low Carbon Fuel Standards (LCFS). Mr. Kahlbaum also maintains and performs all of the analyses of AIR's extensive ambient air and fuel quality databases. He provides meteorological, instrumentation, and data analysis support for Entergy's Palisades Nuclear Plant. In 1995, he was awarded the John Capanius Holm Award by the U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration, which is the highest civilian honor given in recognition of co-operative observational meteorologists.

Attachment 2

Discussion of Cooled EGR as a Technology to Increase Engine Efficiency
Sections 5.2.2.8 and 5.2.2.9 of EPA/NHTSA/CARB "Draft Technical Assessment Report"
Transportation Fuels Consulting, Inc.
September 19, 2016

Engine downsizing and downspeeding have been widely discussed in the recent technical literature as a means of complying with the first 4 to 5 years of the 2017 to 2025 Corporate Average Fuel Economy (CAFE) and Greenhouse Gas (GHG) Emission regulations. Increased compression ratio with high octane fuel and cooled EGR have been identified as key technologies to enable downsized, downspeeded engines in order to address engine knock associated with the higher operating loads of these engines. Among the technologies evaluated by EPA in its draft Technical Assessment Report (TAR), exhaust gas recirculation (EGR) was discussed as a means of improving engine efficiency and thereby reducing CO2 emissions and improving fuel economy. More specifically, it was implied that cooled EGR (cEGR) alone could be employed instead of high octane fuel as a means of controlling engine knock in downsized, boosted engines operating at high compression ratios and high loads[1].

The potential for using cEGR as an alternative to high octane fuels has been discussed[2], but the lack of research specifically addressing the two technologies as alternatives was acknowledged. Also, several manufacturers have specified the use of high octane fuels in addition to cEGR, having apparently determined that cEGR alone was not adequate to permit operation of 24 and 27 bar BMEP boosted engines on regular grade 87 AKI gasoline. In its draft Technical Assessment Report (TAR), EPA devotes considerable discussion to Mazda "SkyActive" Atkinson Cycle technology and its ability to achieve very high efficiencies. One example was said to use a compression ratio of 14.0:1 and cEGR to address engine knock, however the premium high octane fuel requirement at that compression ratio was not mentioned.

EPA and NHTSA have apparently proposed the use of cEGR with high compression ratio engines as an alternative to high octane premium grade fuel in 24 to 27 bar BMEP engines. While the technical literature confirms that engine efficiencies can be improved by the use of cEGR and by the use of high octane fuels, no studies have indicated that either technology alone can be as effective as the use of the two in combination.

Recent in-depth research has been undertaken by the U.S. Department of Energy Vehicle Technologies Office, Bioenergy Technologies Office and the National Laboratories with the goal of developing new fuels and engine architectures that are co-optimized, i.e. designed in tandem to maximize efficiency and

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[1] Draft Technical Assessment Report: Midterm Evaluation of Light-Duty Vehicle Greenhouse Gas Emission Standards and Corporate Average Fuel Economy Standards for Model Years 2022-2025, U.S. Environmental Protection Agency, National Highway Traffic Safety Administration, California Air Resources Board, July 2016, Sec. 5.2.2.8 to 5.2.2.9.

[2] Cost, Effectiveness and Deployment of Fuel Economy Technologies for Light-Duty Vehicles, Committee on the Assessment of Technologies for Improving Fuel Economy of Light-Duty Vehicles, Phase 2, National Academies of Science, ISBN 978-0-309-37388-3.

reduce carbon emissions. This extensive research program is pertinent to the question of technologies needed to enable compliance with the 2017 to 2025 CAFE and GHG regulations. Recent research performed under the Co-Optima program at Oak Ridge National Laboratory (ORNL) dealing with high compression engines with high octane fuels and cEGR was recently reported.

Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR[3]

A study was performed at Oak Ridge National Laboratory Fuels, Engines and Emissions Research Center on a single cylinder turbocharged direct injection research engine at 11.85:1 compression ratio using three fuels, 87 AKI gasoline, 97 RON 24 percent isobutanol (IB24) and 100 RON 30 percent ethanol (E30). Experiments were conducted with all three fuels at engine loads ranging to full load conditions and five engine speeds (1200, 1600, 2000, 2500, and 3000 RPM) with both zero EGR and 15 percent external, cooled EGR.

Fuel Properties	**87 AKI**	**IB24**	**E30**
RON	90.2	96.6	100.3
MON	83.9	86.8	88.8
HoV (kJ/kg)	352	470	599
Specific Gravity	0.729	0.742	0.745
Vol. Energy Density (MJ/gal)	119.5	114.5	107.1

The research by Splitter and Szybist at ORNL determined that a combination of high octane fuel and cEGR technologies was complimentary and more beneficial than either technology alone:

- EGR provided thermal advantages and was a key enabler of increased engine efficiency for all three fuels. With all three fuels, 15 percent EGR increased engine efficiency by reducing pumping losses and increasing gross thermal efficiency.

- E30 high octane fuel provided the highest torque in combination with 15 percent EGR.

- cEGR alone did not offer as much increase in efficiency as E30 since higher load operation was permitted by the unique knock mitigation capability of ethanol.

- E30 was found to increase EGR tolerance, i.e. EGR could be used across broader ranges of engine speeds and loads without incurring combustion instability.

- Unique properties of ethanol doubled torque capability with E30 compared to 87 AKI gasoline.

- The data suggested that engine and vehicle optimization with mid-level ethanol blends such as E30 can allow for offsetting the reduced fuel energy content compared to gasoline, and likely reduce fuel consumption and CO2 emissions as well.

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[3] Splitter, D. and Szybist, J., Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR, ACS Publications, December 21, 2013.

Recent research in the technical literature clearly indicates that 15 percent cooled EGR in combination with high octane fuel and high compression enables engine efficiency, engine downsizing and downspeeding that could not be obtained with cEGR alone. The research also indicates that the combination of these technologies is likely to be used extensively as a means of complying with the 2017 to 2025 CAFE and GHG regulations.

Vehicle testing is currently underway at ORNL to evaluate the fuel economy and CO2 emission benefits of E25 high octane mid-level ethanol blend fuel with a high compression ratio engine and simulated downsized and downspeeded vehicle configuration. Preliminary data appears to demonstrate the benefits of the technology that are consistent with the AIR analysis of benefits and costs[4]. Complete results are expected to be available near the end of 2016.

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[4] Evaluation of Costs of EPA's 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines, AIR, Inc., September 14, 2016