Evaluation of Costs of EPA's 2022-2025 GHG Standards
With High Octane Fuels and Optimized High Efficiency Engines
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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 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]

[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.
[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".

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. 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 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

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[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.

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.

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.

[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.

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 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

[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.

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

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.

[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.

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.

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.

[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.

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.

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%

[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.

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 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%.

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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.

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)

For the purposes of this analysis, we will assume a $50 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

[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.

[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.

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 of the blendstock. The formula is $P_B = (P_{E10} - 0.1 \text{ X } P_E) / 0.9$ 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 $P_{E25} = (0.25 \text{ X } P_E) + (0.75 \text{ X } P_B)$ 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.

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

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

[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.

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.
    - 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.

[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.

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.

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 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]

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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.

[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.

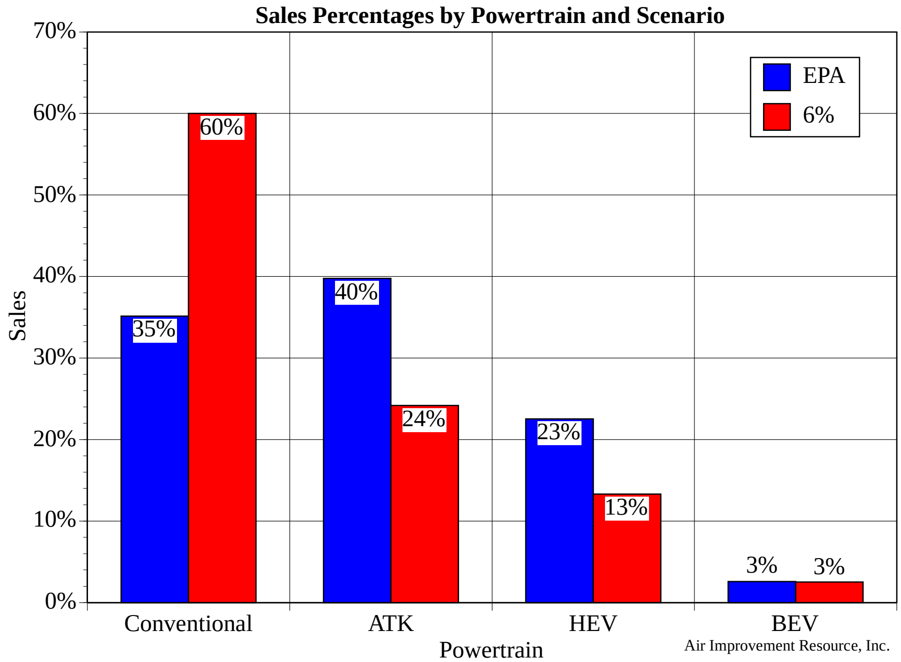
Table 12. Impact of HCR on Model Year 2025 Vehicle Costs		
Item	Without Higher Compression Ratio	With Higher Compression Ratio
Sales	16,419,435	16,419,435
Total Cost Billion ($)	23.4	16.8
Average per vehicle cost $/vehicle	$1,425	$1,021
CO_2 Target (g/mi)	198.83	198.83
Final CO_2 (g/mi)	197.79	197.75

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).

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

[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.”

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

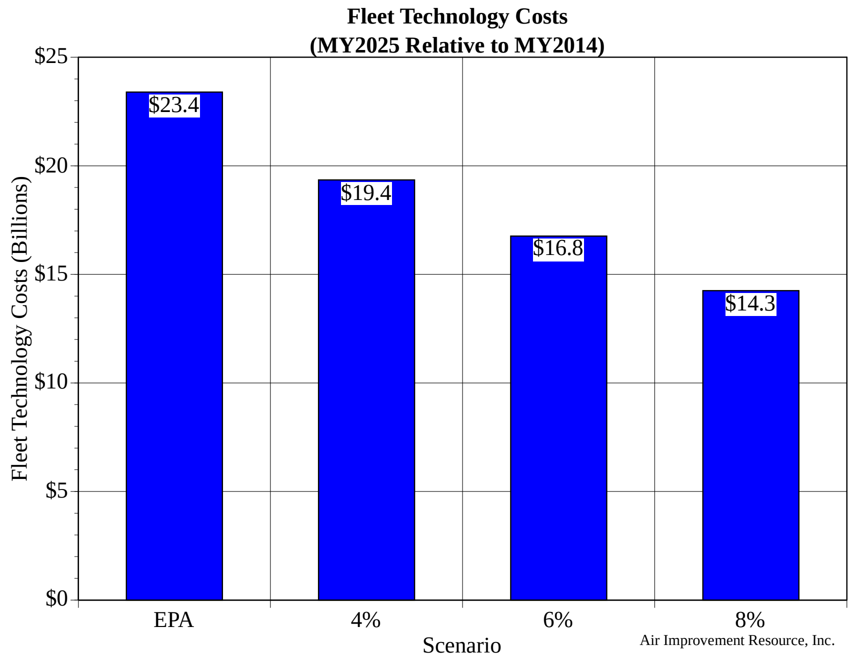


Figure 3

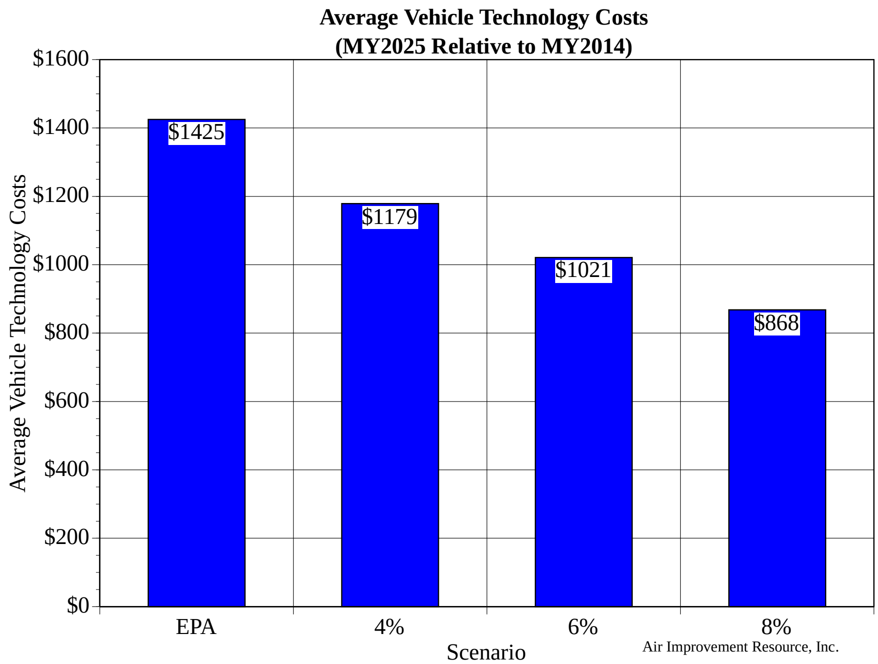


Figure 4

Average Vehicle Technology Costs by Powertrain and Scenario (MY2025 Relative to MY2014)

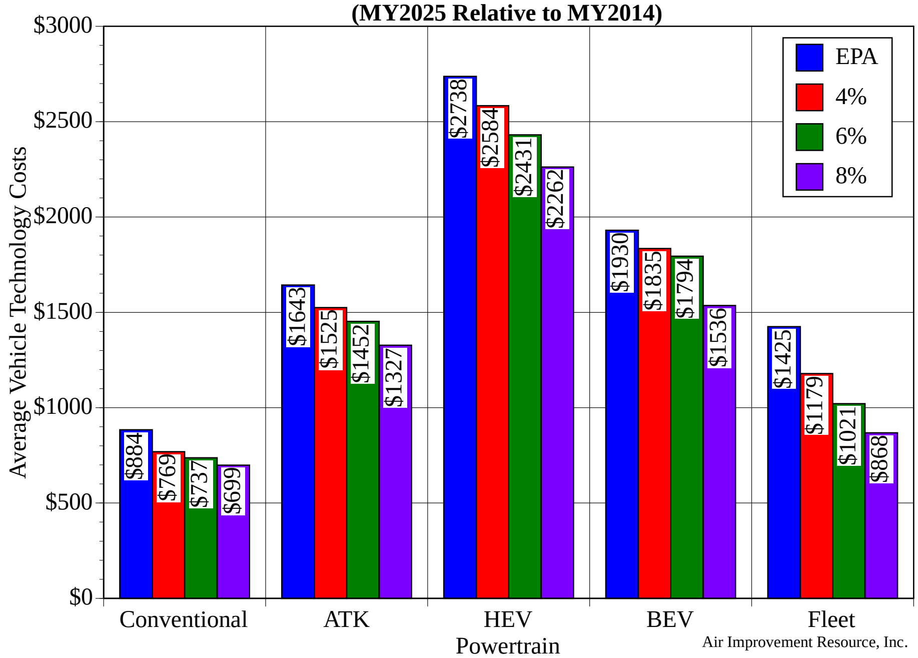
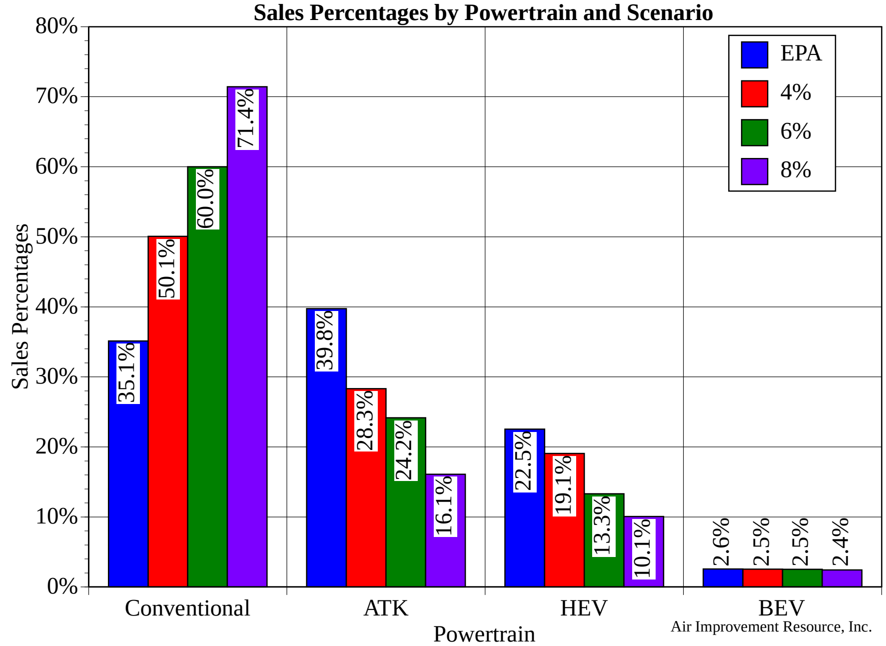


Figure 5

Sales Percentages by Powertrain and Scenario



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 $50 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%