To: **Environmental Protection Agency (EPA)**

From: **Robin Vercruse, Vice President of Policy and Environment, Fuel Freedom Foundation**

Re: **EPA Docket ID: EPA-HQ-OAR-2015-0827**
82 Fed. Reg. 39551 (Aug. 21, 2017)
Submitted via http://regulations.gov

These comments are submitted on behalf of Fuel Freedom Foundation, in response to the **Request for Comment on Reconsideration of the Final Determination of the Mid-Term Evaluation of Greenhouse Gas Emissions Standards for Model Year 2022-2025 Light-Duty Vehicles; Request for Comment on Model Year 2021 Greenhouse Gas Emissions Standards** issued on August 21, 2017.

Fuel Freedom Foundation is a non-profit 501(c)(3) organization that conducts research and advocates for policies that will increase diversity and promote market competition when it comes to transportation fuels, in particular for cars and light-duty trucks. Fuel Freedom believes that focusing on fuels as well as vehicle technology in the Midterm Evaluation (MTE) will help to achieve a number of important National Program and U.S. policy goals:

- A more flexible and cost-effective approach for reducing emissions of greenhouse gases (GHGs)
- Improved national security by reducing our dependence on foreign oil;
- Improved public health by reducing emissions of toxic and criteria air pollutants; and
- Increased economic opportunities generated by greater deployment of U.S. domestic sources of fuel.

All these goals are vital to our national interests. For that reason, Fuel Freedom supports EPA's decision to reconsider the January 2017 Midterm Evaluation Final Determination that the light-duty vehicle greenhouse gas standards previously established for model years 2022-2025 are appropriate under section 202(a) of the Clean Air Act. Reconsideration is necessary because EPA, in its rushed Final Determination, did not address key issues that could have minimized the economic impact of the standards on consumers, better facilitated consumer choice when it comes to vehicles and fuels, and increased assurance of meeting National Program goals.

In reconsidering the Final Determination, EPA can make progress in accord with National Program goals while also keeping in mind greater U.S. national policy goals. Specifically, EPA can continue a trajectory of GHG reductions and higher fuel economy while also seeking to minimize cost to consumers, maintain consumer choice and enhance market competition when it comes to vehicles and fuels, enhance U.S. economic opportunities, and produce American jobs. Reconsidering the Final Determination gives EPA the opportunity to more thoroughly and holistically consider the benefits and costs of the ambitious fuel economy and GHG emissions standards.

Fuel Freedom takes no position on whether the 2022-2025 standards are adequate or whether EPA should make any changes to the 2021 standard. The technical studies related to the MTE should provide the basis for those determinations. **However, as EPA and the National Highway Traffic Safety Administration (NHTSA) consider these standards during the MTE, in response to EPA's specific request for comment on high-octane fuels, we strongly urge the agencies to take into account the**

benefits of high-octane fuel and ensure that steps are taken to enable automakers and consumers to take advantage of those benefits by 2022.

Fuel Freedom is also concerned that EPA and NHTSA selectively promote certain vehicle technologies, while ignoring or neglecting more cost-effective options which can and should be welcomed to provide for the entire range of consumer choices and the greatest regulatory compliance flexibility. Electric vehicles (EVs) and compressed natural gas (CNG) vehicles, are favored, yet even under the most optimistic projections for such vehicles supported by attractive market and regulatory incentives, vehicles with spark-ignited internal combustion engines (ICEs) are projected to dominate U.S. roadways well beyond 2025. For this reason, Fuel Freedom believes that EPA and NHTSA must focus on cost-effective improvements that can be made to vehicles with ICEs. This cannot be done without considering the fuels that will power those vehicles.

As part of its reconsideration, EPA should:

- Work with NHTSA and the California Air Resources Board (CARB) to maintain one National Program for regulating GHG emissions from cars and light-duty trucks.
- Address the role that high-octane fuels can play in achieving MY2022-2025 GHG standards and in standards likely to apply beyond 2025.
- Provide for an orderly national transition to higher-octane fuel.
- Revisit GHG program incentives for 2017-2025 in light of the current vehicle-fuel technology and market realities.

I. Changing Economic Realities Have Had a Substantial Effect on Consumer Behavior and Must be Addressed.

Since 2012, when the current 2022-2025 standards were established, the light-duty transportation sector has shifted significantly, undermining some of the core assumptions on which those standards were based. Most notably, oil prices have fallen substantially and have remained low in relative terms for a sustained period. It has become apparent that fuel prices have a significant impact on consumer behavior. As noted in 2016 draft Technical Assessment Report (TAR), consumers have shifted toward larger vehicles with internal combustion engines and away from smaller or alternative technology vehicles such as electrics or hybrids. Despite generous incentives, demand for alternative vehicle technology has not kept pace with the expectations of 2012.

Current market realities are consistent with projections that ICE vehicles will dominate the roadways – in the U.S. and around the world – for decades to come. This does not mean that EPA or NHTSA should decrease ambitions to reduce GHG emissions or improve fuel economy, but they should not unduly restrict the ability of automakers to provide the full range of vehicles that satisfy consumer needs and preferences. Consumers who prefer alternative vehicle technologies should be able to purchase them, and automakers should get full credit for producing them. At the same time, EPA and NHTSA must give equal attention to ICE vehicles and facilitate their ability to comply with increasingly stringent standards. This means that, in reconsidering the Final Determination, EPA and NHTSA must consider the full range of ICE technology options and the fuels that are needed to enable them.

II. Higher Octane Fuels Are a Demonstrated, Cost-effective Way to Achieve GHG Reductions and Greater Fuel Efficiency While Maintaining Consumer Choice in Vehicles and Engines.

Engines and fuels work together in concert to determine the performance, including the fuel efficiency and emissions performance, of any vehicle. Yet U.S. fuel economy and tailpipe GHG regulations have to date focused exclusively on engine and vehicle technologies. As a result, although automakers have made great strides in advancing engine technology, they have done so without the benefit of higher-octane fuel that is widely available in other parts of the world.

In the 2016 draft TAR, which provides the basis for the Final Determination, EPA and NHTSA assume that ICE technologies use only 87 anti-knock index (AKI) gasoline. As a result, EPA has ignored the potential of higher-octane-fueled ICEs to help improve fuel economy or reduce GHG emissions. Instead of considering only vehicle and engine technologies for MY2022-2025, EPA should take a more holistic perspective to consider the range of vehicle, engine, and fuel technologies currently on the horizon. EPA's analysis must include an assessment of the costs and benefits from promising high-octane ICE technologies, like high compression engines, that are either already in the market or reasonably foreseeable in the near future.

Higher-octane fuel, especially when coupled with high-compression engines, is one of the most cost-effective pathways for reducing oil consumption and reducing GHG emissions. In a 2015 study commissioned by NHTSA, the National Research Council of the National Academy of Sciences concluded that higher-octane fuels are a low-cost option for reducing fuel consumption and GHG emissions in light-duty spark-ignition engines, both on their own and when used with higher compression ratio engines.[1] Yet EPA inexplicably failed to include this pathway in the prematurely closed MTE analysis, despite strong support from stakeholders. We applaud the EPA for reversing course in specifically requesting comments on high-octane fuel. **Fuel Freedom continues to believe that the EPA should consider available and potentially available fuels that can enable the use of, or greater use of, technologies that would increase fuel efficiency and decrease CO_2 emissions in line with National Program goals.**

The Department of Energy (DOE) Co-Optima program has already demonstrated the efficiency and GHG reduction benefits of optimizing vehicles and fuels in tandem. In addition, the wealth of credible, peer-reviewed information available justifies including higher-octane fuel and engine technologies enabled by it in EPA's analysis of the MY2022-2025 GHG standards.[2] These studies show the benefits of higher octane and higher heat of vaporization on ICE efficiency. Higher-octane fuels enable existing vehicles equipped with a knock sensor to advance spark timing and improve efficiency, and they allow the design of new vehicles with higher compression to further increase engine efficiency and enable additional improvements with additive technologies such as downsizing and hybridization.

Several studies in this body of research show that the combination of high compression ratio engines and high-octane fuels leads to greater fuel efficiency. Further, the combined CO_2 emissions benefits of high-compression ratio with high octane can exceed the sum of their individual CO_2 reductions. Appendix A attached to these comments summarizes the robust body of research and justifies the inclusion of these technologies in EPA's MTE analysis: they are well known, nearly market-ready in automotive terms, and have shown great promise for increased efficiency and CO_2 reductions.

[1] NAS, *Cost, Effectiveness and Deployment of Fuel economy Technologies for Light-Duty Vehicles* (2015).
[2] An appendix summarizing this research is attached to these comments as Appendix A

EPA itself has recognized that high-octane fuels "could help manufacturers that wish to raise compression ratios to improve vehicle efficiency, as a step toward complying with the 2017 and later light-duty greenhouse gas and CAFE standards."[3] The fuel economy and CO_2 emissions performance of the technologies EPA did analyze can be improved when used in conjunction with premium gasoline (93 AKI or ~97 RON), or with even higher-octane fuels (~100 RON), including mid-level ethanol blends. **This means that greater availability of high-octane fuels can increase assurance that National Program standards are achieved.** Nonetheless, the agency had not previously considered high-octane fuels as part of the MTE. Nor has it taken any of the steps that will be needed to ensure an orderly phase-in of such fuel.

EPA must consider the important role that high-octane fuel can play in achieving the goals of the National Program. Better fuels will not only facilitate cost-effective compliance with the 2022-2025 standards and facilitate continued progress beyond 2025, but will also ensure that consumers continue to have affordable vehicle options that meet their needs.

In the near-term, high-octane fuels can be produced cost-effectively from a combination of petroleum and ethanol, or from the refinery. Ethanol blends increase engine efficiency due to higher octane and other favorable properties such as higher heat of vaporization. Oak Ridge National Lab found that if mid-level ethanol blends provide the necessary octane, "engine and vehicle optimization can offset the reduced fuel energy content… and likely reduce vehicle fuel consumption and tailpipe CO_2 emissions."[4] Additional research supports this;[5] and at least one study has concluded that the wide-scale use of high-octane fuels (98 RON) could result in a potential fleet-wide 4.5% decrease in fuel consumption by 2040.[6]

III. EPA Should Implement an Orderly National Transition to Higher-Octane Fuel that Would Serve the Purposes of the National Program.

The market share of premium fuel (91-93 AKI) in the U.S. has increased in recent years. Even so, these premium fuels are only about 12% of the market. As the NAS report suggests, more must be done to increase their availability and move these fuels from a niche offering only available to consumers willing to pay a significant premium – a premium that is not justified by the cost of producing or getting the fuel to market. Recognizing that it can take years for an increase in octane to penetrate the marketplace, EPA should begin to take steps now to raise the minimum octane so that the benefits of higher-octane fuels can be realized by 2022.

EPA and CARB have each acknowledged their authority to approve appropriate higher-octane fuels and phase in minimum octane standards over time.[7] These agencies should use that authority to decrease and ultimately eliminate the availability of low-octane fuels unsuitable for advanced engine

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[3] 78 Fed. Reg. 29815, 29825 (May 21, 2013).

[4] Splitter, D., Szybist, J., *Intermediate Alcohol-Gasoline Blends, Fuels for Enabling Increased Engine Efficiency and Powertrain Possibilities* (Apr. 1, 2014).

[5] *See* Jung, H., Leone, T., Shelby, M., Anderson, J. et al., *Fuel Economy and CO2 Emissions of Ethanol-Gasoline Blends in a Turbocharged DI Engine* (Apr. 8, 2013); West, B., Szybist, J., Theiss, T., et. al., Summary of High-Octane Mid-Level Ethanol Blends Study at 10 (July 2016).

[6] Chow, E., Heywood, J., Speth, R., *Benefits of a Higher Octane Standard Gasoline for the U.S. Light-Duty Vehicle Fleet* (Apr. 1, 2014).

[7] Machiele P., *Mobile Sources Technical Review Subcommittee [Presentation]* at 9-10 (May 5, 2015), *available at* https://www.epa.gov/sites/production/files/2016-01/documents/mstrs_050515summary.pdf; Machiele P., *DOE Sustainable Transportation Summit [Interview]* (July 12, 2016); CARB, *Presentation to Clean Air Act Advisory Committee, Mobile Sources Technical Review Subcommittee,* Slide 10 (May 5, 2015).

technologies. Fuel Freedom recognizes that this process can take many years due to the need to (1) develop and approve fuel formulations; (2) adopt ASTM engine testing specifications; (3) design and certify engines for use; (4) add fueling infrastructure; and (5) provide for transition time in the market. However, some of this lead time can be offset because current gasoline infrastructure could be modified to handle either petroleum-derived high-octane fuels or higher ethanol blends such as a mid-level E25-E40.

The transition to high-octane ethanol blends may be facilitated by the 20 million flexible fuel vehicles (FFVs) on the road today – vehicles that are compatible with any blend of ethanol and gasoline up to E85. These FFVs would provide a foothold for matching fuels and vehicles in a high octane transition.[8] Nevertheless, given the long lead time needed to change the fuel supply, pushing consideration of higher-octane fuels to beyond 2025 would be a mistake when EPA now has the opportunity to begin a gradual nationwide shift to high-octane fuels. We urge EPA to take action on this issue as part of the process for reconsidering the MY2022-2025 standards.

IV. EPA Should Revisit GHG Program Incentives for 2017-2025 in Light of the Current Vehicle-Fuel Technology and Market Realities.

Fuel Freedom is also concerned that EPA and NHTSA have selectively favored specific vehicle technologies. To date, EPA's analysis of technology that might be important after 2025 has selectively discussed only EVs and hydrogen fuel cell electric vehicles (FCEVs). Fuel Freedom believes that the EPA and NHTSA should support all technologies that can help meet national goals, including ICE technologies and the fuels needed to power them. Critically, high-octane fuels can enable engine advancements in the future – without negatively impacting the maturation and growth of alternative vehicle technologies.[9]

As noted above, ICEs are expected to dominate the roadways for decades – in the U.S. and especially worldwide.[10] Even if wealthier countries were to require consumers to purchase more expensive alternative technologies, ICE vehicles will account for the vast majority of the increase projected for the worldwide vehicle fleet over the next several decades. Technology development for ICEs in the U.S. will substantially influence GHG emissions from the growing worldwide fleet of cars and light-duty trucks, and the U.S. should encourage the development of cost-effective technologies for reducing fuel use and GHG emissions from ICEs.

Even in the U.S., the average age for light-duty vehicles has increased to 11.4 years.[11] As a consequence, advances in ICE technology between now and 2025 will have a substantial impact on fuel economy and GHG emissions well beyond that time. Yet the current standards do not provide an incentive for higher-octane fuels.

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[8] It is important to note that production of FFVS is rapidly declining due to the sunset of both CAFE and GHG program credits for FFVs. EPA and NHTSA should consider regulatory incentives that could reverse this trend.

[9] A recent study found that greater use of high compression engines to meet the MY2025 standards will not only lower compliance costs, but will do so without hindering consumer adoption of EVs. *See* Air Improvement Resources, *Evaluation of Costs of EPA's 2022-2025 GHG Standards With High Octane Fuels and Optimized High Efficiency Engines* (Sept. 16, 2016).

[10] EIA, *Annual Outlook 2016: Light Duty Vehicle Stock by Technology Type* (2017), https://www.eia.gov/outlooks/aeo/data/browser/#/?id=49-AEO2017&cases=ref2017&sourcekey=0.

[11] DOT, *National Transportation Statistics* (Apr. 2016).

Fuel Freedom supports the entire range of alternative fuel vehicles, but believes that liquid-fueled ICE technologies merit consideration for incentives to complement the proposed credits for EV, FCEV and CNG technologies. Recent evidence shows that circumstances can intercede to undermine projections of fleet average CO_2 reductions. As noted in the TAR, lower gasoline prices have reduced sales of hybrids and alternative fuel vehicles, in conjunction with an uptick in sales of light trucks. Appropriate incentives could provide a 'hedge' or insurance policy for progress toward National Program goals.

We do not propose specific GHG or CAFE credit schemes. Appropriate incentives should be negotiated between the agencies and automakers as the regulated parties. However, offering a regulatory credit to automakers for using materials that are compatible with higher alcohol blends could trigger a market-driven response to ease adoption of higher-octane fuels. While octane can come from the refinery, ethanol is currently the cheapest and cleanest source of high octane. Material compatibility with alcohol blends can ensure that engines can take advantage of any octane that the market provides. Manufacturing compatible engines and components adds little cost, but the phase-out of the FFV CAFE credit means automakers have no incentive to incur any additional costs.

V. Other Measures to Promote High-octane Fuels.

Fuel Freedom also supports any other measures by the agencies that can facilitate widespread adoption of higher-octane fuels. In particular, the EPA should give priority to certifying midlevel ethanol blends that can enter the marketplace to compete with other high-octane gasoline. The Renewables Enhancement and Growth Support (REGS) rule proposed by EPA in October 2016 contains provisions that could simplify the certification and approval process of such midlevel blends. Fuel Freedom strongly encourages EPA to proactively develop and/or approve midlevel ethanol formulations that satisfy the necessary properties and criteria for commerce.

Appendix A: Summary of high-octane research

The Competitive Position of Ethanol as an Octane Enhancer
Authors: S. Irwin, D. Good
"The recent rise of ethanol prices above gasoline prices has raised the specter of ethanol losing its place as the cheapest source of octane. While this would not necessarily limit ethanol consumption due to the existence of the RFS conventional ethanol mandate, it would have implications for the cost of complying with the RFS mandates. To assess any changes in the competitive position of ethanol in gasoline blends, the price of the aromatic compounds benzene, toluene, and xylene were analyzed relative to the price of ethanol. These compounds have octane ratings generally similar to that of ethanol and have a long history as octane enhancers in gasoline blends. Despite the recent increase in ethanol prices relative to gasoline, ethanol prices still remain below that of the aromatics. As a result, ethanol continues to retain its position as the low cost octane enhancer in gasoline blends."
http://farmdocdaily.illinois.edu/2016/02/ethanol-position-as-octane-enhancer.html

Economic and Environmental Benefits of Higher-Octane Gasoline (2014)
Authors: R.L. Speth, E.W. Chow, R. Malina, S.R.H. Barrett, J.B. Heywood, W.H. Green (MIT Study)
"We find that greater use of high-RON gasoline in appropriately tuned vehicles could reduce annual gasoline consumption in the U.S. by 3.0–4.4%. Accounting for the increase in refinery emissions from production of additional high-RON gasoline, net CO2 emissions are reduced by 19–35 Mt/y in 2040 (2.5–4.7% of total direct LDV CO2 emissions). For the strategies studied, the annual direct economic benefit is estimated to be $0.4–6.4 billion in 2040, and the annual net societal benefit including the social cost of carbon is estimated to be $1.7–8.8 billion in 2040."
http://pubs.acs.org/doi/abs/10.1021/es405557p

The Effect of Compression Ratio, Fuel Octane Rating, and Ethanol Content on Spark-Ignition Engine Efficiency
Authors: T.G. Leone, J.E. Anderson, R.S. Davis, A. Iqbal, R.A. Reese, II, M.H. Shelby, and W.M. Studzinski
"New vehicle trends to improve efficiency include higher compression ratio, downsizing, turbocharging, downspeeding, and hybridization, each involving greater operation of spark-ignited (SI) engines under higher-load, knock-limited conditions. Higher octane ratings for regular-grade gasoline (with greater knock resistance) are an enabler for these technologies. This literature review discusses both fuel and engine factors affecting knock resistance and their contribution to higher engine efficiency and lower tailpipe CO2 emissions. Increasing compression ratios for future SI engines would be the primary response to a significant increase in fuel octane ratings. Existing LDVs would see more advanced spark timing and more efficient combustion phasing. Higher ethanol content is one available option for increasing the octane ratings of gasoline and would provide additional engine efficiency benefits for part and full load operation."
http://pubs.acs.org/doi/abs/10.1021/acs.est.5b01420?journalCode=esthag

Effects of Fuel Octane Rating and Ethanol Content on Knock, Fuel Economy, and CO2 for a Turbocharged DI Engine (2014)
Authors: T.G. Leone, E.D. Olin, J.E. Anderson, H.H. Jung, M.H. Shelby, R.A. Stein (Ford, AVL Powertrain Engineering study)
"The data were used in a vehicle simulation of a 3.5L EcoBoost F150, which showed that E20-96 RON at 11.9:1 CR offers 5% improvement in tailpipe CO2 emissions and 1% improvement in miles per gallon (MPG) fuel economy relative to E10-91RON at 10:1 CR. E30-101 RON at 13:1 CR in this vehicle yielded 6−9% improvement in CO2 emissions and 2% worse to 1% better MPG fuel economy, depending

on the drive cycle."
http://papers.sae.org/2014-01-1228/

Effects of High-Octane Ethanol Blends on Four Legacy FlexFuel Vehicles, and a Turbocharged GDI Vehicle (2015)
Authors: J.F. Thomas, B. West, S.P. Huff
"Experiments were performed with four FFVs using a 10% ethanol fuel (E10) with 88 pump octane, and a market gasoline blended with ethanol to make a 30% by volume ethanol fuel (E30) with 94 pump octane. The research octane numbers were 92.4 for the E10 fuel and 100.7 for the E30 fuel. Two vehicles had gasoline direct injected (GDI) engines, and two featured port fuel injection (PFI). Significant wide open throttle (WOT) performance improvements were measured for three of the four FFVs, with one vehicle showing no change. Additionally, a conventional (non-FFV) vehicle with a small turbocharged direct injected engine was tested with a regular grade of gasoline with no ethanol (E0) and a splash blend of this same fuel with 15% ethanol by volume (E15). RON was increased from 90.7 for the E0 to 97.8 for the E15 blend. Significant wide open throttle and thermal efficiency performance improvement was measured for this vehicle, which achieved near volumetric fuel economy parity on the aggressive US06 drive cycle, demonstrating the potential for improved fuel economy in forthcoming downsized, downsped engines with high-octane fuels."
http://info.ornl.gov/sites/publications/files/Pub54888.pdf

Effects of Mid-Level Ethanol Blends on Conventional Vehicle Emissions (2009)
Authors: K. Knoll, B. West, S. Huff, J. Thomas, J. Orban, C. Cooper
"For the aggregate 16-vehicle fleet, increasing ethanol content resulted in reductions in average composite emissions of both NMHC and CO and increases in average emissions of ethanol and aldehydes. Changes in average composite emissions of NMOG and NOX were not statistically significant. By segregating the vehicle fleet according to power-enrichment fueling strategy, a better understanding of ethanol fuel-effect on emissions was realized. Vehicles found to apply long-term fuel trim (LTFT) to power-enrichment fueling showed no statistically significant fuel effect on NMOG, NMHC, CO or NOX. For vehicles found to not apply LTFT to power-enrichment, statistically significant reductions in NMHC and CO were observed, as was a statistically significant increase in NOX emissions. Effects of ethanol on NMOG and NMHC emissions were found to also be influenced by power-to-weight ratio, while the effects on NOX emissions were found to be influenced by engine displacement."
http://papers.sae.org/2009-01-2723/

Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR. 1. Engine Load Range and Downsize Downsized Opportunity (2014)
Author: D.A. Splitter, J.P. Szybist
"Data suggest that, with midlevel alcohol–gasoline blends, engine and vehicle optimization can offset the reduced fuel energy content of alcohol–gasoline blends and likely reduce vehicle fuel consumption and tailpipe CO2 emissions."
http://pubs.acs.org/doi/abs/10.1021/ef401574p

Experimental Investigation of Spark-Ignited Combustion with High-Octane Biofuels and EGR. 2. Fuel and EGR Effects on Knock-Limited Load and Speed (2014)
Authors: D.A. Splitter, J.P. Szybist
"The results illustrate that intermediate alcohol–gasoline blends exhibit exceptional antiknock properties and performance beyond that indicated by the octane number tests, particularly

E30."
http://pubs.acs.org/doi/abs/10.1021/ef401575e

Exploring the Relationship Between Octane Sensitivity and Heat-of-Vaporization (2016)
Authors: C.S. Sluder, J.P. Szybist, R.L. McCormick, M.A. Ratcliff, B.T. Zigler (ORNL, NREL study)
"New studies were performed at ORNL and NREL to further investigate the relationship between HoV and octane sensitivity. Three fuels were formulated for the ORNL study with matched RON and octane sensitivity, but with differing HoV. Experiments with these fuels in a 1.6-liter GTDI engine showed that the fuels exhibited very similar combustion phasing under knock-limited spark advance (KLSA) conditions. Fuels having a range of RON, octane sensitivity, and HoV were tested at NREL in a single-cylinder GDI engine under conditions where octane sensitivity has little effect on knock resistance. KLSA was found to be well correlated with RON. These results reinforce the concept that HoV anti-knock effects can be viewed as a contributor to octane sensitivity. From this viewpoint, HoV effects manifest themselves as increases in octane sensitivity."
http://papers.sae.org/2016-01-0836/

Fuel Economy and CO2 Emissions of Ethanol-Gasoline Blends in a Turbocharged DI Engine (2013)
Authors: H.H. Jung, T.G. Leone, M.H. Shelby, J.E. Anderson, T. Collings (Ford Study)
"The data was used in a vehicle simulation of a 3.5L EcoBoost pickup truck, which showed that the E20 (96 RON) fuel at 11.9:1 CR offers 5% improvement in U.S. EPA Metro-Highway (M/H) and US06 Highway cycle tank-to-wheels CO_2 emissions over the E10 fuel, with comparable volumetric fuel economy (miles per gallon) and range before refueling. The results also indicated that the E30 (101 RON) fuel at 11.9:1 CR provides improvements in CO_2 emissions of 5% on the EPA M/H cycle and 7.5% on the US06 Highway cycle, while volumetric fuel economy was 3% lower on the M/H cycle and approximately equal on the US06 Highway cycle, compared to the baseline E10 fuel at 10:1 CR."
http://papers.sae.org/2013-01-1321/

Heat of Vaporization Measurements for Ethanol Blends Up To 50 Volume Percent in Several Hydrocarbon Blendstocks and Implications for Knock in SI Engines (2015)
Authors: G.M. Chupka, E. Christensen, L. Fouts, T.L. Alleman, M.A. Ratcliff, R.L. McCormick
"Blends of ethanol at 10 to 50 volume percent were prepared with three gasoline blendstocks and a natural gasoline. Performance properties and composition of the blendstocks and blends were measured, including research octane number (RON), motor octane number (MON), net heating value, density, distillation curve, and vapor pressure. RON increases upon blending ethanol but with diminishing returns above about 30 vol%. Above 30% to 40% ethanol the curves flatten and converge at a RON of about 103 to 105, even for the much lower RON NG blendstock. Octane sensitivity (S = RON - MON) also increases upon ethanol blending. Gasoline blendstocks with nearly identical S can show significantly different sensitivities when blended with ethanol."
http://papers.sae.org/2015-01-0763/

High-Octane Mid-Level Ethanol Blend Market Assessment (2015)
Authors: C. Johnson, E. Newes, A. Brooker, R. McCormick, S. Peterson, P. Leiby, R.U. Martinez, G. Oladosu, M.L. Brown
"The eight deployment scenarios were modeled by the Automotive Deployment Options Projection Tool (ADOPT) to estimate the adoption rate of HOFVs. As shown in Figure ES-1, all scenarios showed the potential for HOFVs to comprise a substantial percentage (43%–79%) of the light-duty vehicle (LDV) stock by 2035. In general, more HOFVs are adopted if HOF is E40 because they offer greater fuel cost savings and offer vehicle manufacturers a greater GHG emissions benefit than if HOF is E25. … The

modeling analyses concur that feedstock availability and cost are not expected to be obstacles to the substantial development of a HOF market across all of the scenarios considered. In numerous scenarios, HOF costs are sufficiently competitive that substantial market share is attained—up to 75 billion gallons of E40 (30 billion gallons of fuel ethanol) by 2035. This would meet over 60% of LDV fuel demand in that year, given projections from the ADOPT model. However, all scenarios fell short of satisfying 100% of the fuel demanded by LDVs and were therefore limited."
http://www.afdc.energy.gov/uploads/publication/high-octane_mid-level_ethanol_mkt_assessment.pdf

High octane number ethanol–gasoline blends: Quantifying the potential benefits in the United States (2012)
Authors: J.E. Anderson, D.M. DiCicco, J.M. Ginder, U. Kramer, T.G. Leone, H.E. Raney-Pablo, T.J. Wallington
"Higher RON would enable greater thermal efficiency in future engines through higher compression ratio (CR) and/or more aggressive turbocharging and downsizing, and in current engines on the road today through more aggressive spark timing under some driving conditions. Such an approach would differ from the current practice of blending ethanol into a gasoline blendstock formulated with lower octane rating such that the net octane rating of the resulting final blend is unchanged from historical levels."
http://www.sciencedirect.com/science/article/pii/S0016236112002268

The Impact of Ethanol Fuel Blends on PM Emissions from a Light-Duty GDI Vehicle (2011)
Authors: M.M. Maricq, J.J. Szente, K. Jahr
As the ethanol level in gasoline increases from 0% to 20%, there is possibly a small (<20%) benefit in PM mass and particle number emissions, but this is within test variability. When the ethanol content increases to >30%, there is a statistically significant 30%–45% reduction in PM mass and number emissions observed for both engine calibrations. Particle size is unaffected by ethanol level. PM composition is primarily elemental carbon; the organic fraction increases from ∼5% for E0 to 15% for E45 fuel. Engine-out hydrocarbon and NOx emissions exhibit 10–20% decreases, consistent with oxygenated fuel additives. These results are discussed in the context of the changing commercial fuel and engine technology landscapes."
http://www.tandfonline.com/doi/abs/10.1080/02786826.2011.648780

The Impact of Low Octane Hydrocarbon Blending Streams on the Knock Limit of "E85" (2013)
Authors: J.P. Szybist, B. West
"Results show that nearly all ethanol-containing fuels are more resistant to engine knock than UTG-96 (the only exception being the ethanol blend with 49% n-heptane). This allows ethanol blends made with low octane number hydrocarbons to be operated at significantly more advanced combustion phasing for higher efficiency, as well as at higher engine loads. While experimental results show that the octane number of the hydrocarbon blend stock does impact engine performance, there remains a significant opportunity for engine optimization when considering even the lowest octane fuels that are in compliance with the current revision of ASTM D5798 compared to premium-grade gasoline."
http://papers.sae.org/2013-01-0888/

Impacts of mid-level biofuel content in gasoline on SIDI engine-out and tailpipe particulate matter emissions (2011)
Authors: X. He, J.C. Ireland, B.T. Zigler, M.A. Ratcliff, K.E. Knoll, T.L. Alleman, J.T. Tester
"Bi-modal particle size distributions were observed for all operating conditions with peak values at particle sizes of 10 nm and 70 nm. Idle and low-speed / low-load conditions emitted higher total particle

numbers than other operating conditions. At idle, the engine-out particulate matter (PM) emissions were dominated by nucleation mode particles, and the production TWC reduced these nucleation mode particles by more than 50%, while leaving the accumulation mode particle distribution unchanged. At an engine load higher than 6 bar net mean effective pressure (NMEP), accumulation mode particles dominated the engine-out particle emissions, and the TWC had little effect. Compared to the baseline gasoline (E0), E10 does not significantly change PM emissions, while E20 and BU12 both reduce PM emissions under the conditions studied. Iso-butanol was observed to impact PM emissions more than ethanol, with up to 50% reductions at some conditions."
http://digitalscholarship.unlv.edu/renew_pubs/40/

Increasing Biofuel Deployment and Utilization through Development of Renewable Super Premium: Infrastructure Assessment (2014)
Authors: K. Moriarty, M. Kass, T. Theiss
"Retail fueling station equipment is commercially available to accommodate both an E25 and an E25+ fuel. Infrastructure costs to introduce E25 are not expected to be significant, but are much higher for any ethanol blend above E25. Both industry stakeholders and manufacturers are more supportive of an RSP at the E25 level with an octane number around 100. The challenges and barriers faced with RSP are not technical but economic, and are similar to those experienced in the deployment of E15 and E85. The higher level of ethanol in RSP does not make the fueling infrastructure issues any worse—the primary issue is demonstrating compliance with applicable legislation, codes, and standards. Retail station owners will need equipment records to demonstrate compatibility with tanks, pipes, and other associated underground equipment."
http://www.afdc.energy.gov/uploads/publication/increasing_biofuel_deployment.pdf

Intermediate Alcohol-Gasoline Blends, Fuels for Enabling Increased Engine Efficiency and Powertrain Possibilities (2014)
Authors: D.A. Splitter, J.P. Szybist (ORNL study)
"The results demonstrate that E30 may further the downsizing and downspeeding of engines by achieving increased low speed torque, even with high compression ratios. The results suggest that at mid-level alcohol-gasoline blends, engine and vehicle optimization can offset the reduced fuel energy content of alcohol-gasoline blends, and likely reduce vehicle fuel consumption and tailpipe CO_2 emissions."
http://papers.sae.org/2014-01-1231/

Investigation of Knock Limited Compression Ratio of Ethanol Gasoline Blends (2010)
Authors: J.P. Szybist, M. Foster, W.R. Moore, K. Confer, A. Youngquist, R. Wagner
"It was found that at substantially similar engine conditions, increasing the ethanol content of the fuel results in higher engine efficiency and higher engine power. These results can be partially attributed to a charge cooling effect and a higher heating value of a stoichiometric mixture for ethanol blends (per unit mass of air). Additional thermodynamic effects on the ratio of specific heats (\yy) and a mole multiplier are also explored. It was also found that high CR can increase the efficiency of ethanol fuel blends, and as a result, the fuel economy penalty associated with the lower energy content of E85 can be reduced by about twenty percent. Such operation necessitates that the engine be operated in a de-rated manner for gasoline, which is knock-prone at these high CR, in order to maintain compatibility. By using early and late intake valve closing strategies, good efficiency is maintained with gasoline, but peak power is about 33% lower than with E85."
http://papers.sae.org/2010-01-0619/

Light-Duty Vehicle CO2 Targets Consistent with 450 ppm CO2 Stabilization (2014)
Authors: S.L. Winkler, T.J. Wellington, H. Maas, H. Hass (Ford study)
"New light-duty vehicle fuel economy and CO2 regulations in the U.S. through 2025 and in the EU through 2020 are broadly consistent with the CO2 glide paths. The glide path is at the upper end of the discussed 2025 EU range of 68–78 g CO2/km. The proposed China regulation for 2020 is more stringent than the glide path, while the 2017 Brazil regulation is less stringent. Existing regulations through 2025 are broadly consistent with the light-duty vehicle sector contributing to stabilizing CO2 at approximately 450 ppm. The glide paths provide long-term guidance for LDV powertrain/fuel development."
http://pubs.acs.org/doi/abs/10.1021/es405651p

Novel Characterization of GDI Engine Exhaust for Gasoline and Mid-Level Gasoline-Alcohol Blends (2014)
Authors: J.M Storey, S. Lewis, J.P. Szybist, J. Thomas, T. Barone, M. Eibl, E. Nafziger, B. Kaul (ORNL study)
"E30 was chosen to maximize octane enhancement while minimizing ethanol-blend level and iBu48 was chosen to match the same fuel oxygen level as E30. Particle size and number, organic carbon and elemental carbon (OC/EC), soot HC speciation, and aldehydes and ketones were all analyzed during the experiment. A new method for soot HC speciation is introduced using a direct, thermal desorption/pyrolysis inlet for the gas chromatograph (GC). Results showed high levels of aromatic compounds were present in the PM, including downstream of the catalyst, and the aldehydes were dominated by the alcohol blending."
http://papers.sae.org/2014-01-1606/

Octane Benefits (Mobile Source Technical Review Subcommittee) (2015)
Authors: C. Jones (GM)
A presentation by automakers highlighting the benefits of a high octane fuel combined with proper engines.
https://www.epa.gov/sites/production/files/2015-05/documents/050515mstrs_jones.pdf

Octane Response in a Downsized, Highly Boosted Direct Injection Spark Ignition Engine (2014)
Authors: S.M. Remmert, R.F. Cracknell, R. Head, A. Schuetze, A.G.J. Lewis, S. Akehurst, J.W.G. Turner, A. Popplewell (Shell, Univ. of Bath, Jaguar Land Rover study)
"This study demonstrates that fuel octane quality continues to be important for the performance of emerging downsized engine technologies. Furthermore, the trend for continued engine downsizing will increase the potential performance benefit associated with knock resistant fuels."
http://papers.sae.org/2014-01-1397/

Refining Economics of U.S. Gasoline: Octane Ratings and Ethanol Content (2014)
Authors: D.S. Hirshfeld, J.A. Kolb
"Increasing the octane rating of the U.S. gasoline pool (currently ~93 Research Octane Number (RON)) would enable higher engine efficiency for light-duty vehicles (e.g., through higher compression ratio), facilitating compliance with federal fuel economy and greenhouse gas (GHG) emissions standards. The federal Renewable Fuels Standard calls for increased renewable fuel use in U.S. gasoline, primarily ethanol, a high-octane gasoline component. Linear programming modeling of the U.S. refining sector was used to assess the effects on refining economics, CO2emissions, and crude oil use of increasing average octane rating by increasing (i) the octane rating of refinery-produced hydrocarbon blendstocks for oxygenate blending (BOBs) and (ii) the volume fraction (Exx) of ethanol in finished gasoline. The analysis indicated the refining sector could produce BOBs yielding finished E20 and E30 gasolines with

higher octane ratings at modest additional refining cost, for example, ~1¢/gal for 95-RON E20 or 97-RON E30, and 3–5¢/gal for 95-RON E10, 98-RON E20, or 100-RON E30. Reduced BOB volume (from displacement by ethanol) and lower BOB octane could (i) lower refinery CO2 emissions (e.g., ~ 3% for 98-RON E20, ~ 10% for 100-RON E30) and (ii) reduce crude oil use (e.g., ~ 3% for 98-RON E20, ~ 8% for 100-RON E30)."
http://pubs.acs.org/doi/abs/10.1021/es5021668

Renewable Oxygenate Blending Effects on Gasoline Properties (2011)
Authors: E. Christensen, J. Yanowitz, M. Ratcliff, R.L. McCormick
"Chemical and physical properties of the blends were compared to the requirements of ASTM specification D4814 for spark-ignited engine fuels to determine their utility as gasoline extenders. Vapor pressure, vapor lock protection, distillation, density, octane rating, viscosity, and potential for extraction into water were measured. Blending of ethanol at 3.7% oxygen increased vapor pressure by 5–7 kPa as expected. 2-Propanol slightly increased vapor pressure in the lowest-volatility BOB, while all other oxygenates caused a reduction in vapor pressure of up to 10 kPa. Coefficients for the Wilson equation were fitted to the measured vapor pressure data and were shown to adequately predict the vapor pressure of oxygenate–gasoline blends for five individual alcohols and MTHF in different gasolines. Higher alcohols and other oxygenates generally improved vapor lock protection. Butyl levulinate blended at 2.7% oxygen caused the distillation end point to exceed 225 °C, thus failing the specification. Distillation parameters were within specification limits for the other oxygenates tested. Other than ethanol, MF, and DMF, the oxygenates examined will not produce blends with satisfactory octane ratings at these blend levels when blended into lower-octane blendstocks designed for ethanol blending. However, all oxygenates tested except 1-pentanol and MTHF produced an increase in octane rating."
http://pubs.acs.org/doi/abs/10.1021/ef2010089

Summary of High-Octane, Mid-Level Ethanol Blends Study (2016)
Authors: T. Theiss, T. Alleman, A. Brooker, A. Elgowainy, G. Fioroni, J. Han, S. Huff, C. Johnson, M. Kass, P. Leiby, R.U. Martinez, R. McCormick, K. Moriarty, E. Newes, G. Oladosu, J.P. Szybist, J. Thomas, M. Wang, B. West
"The experimental and analytical results of this study considered together show that HOF, specifically mid-level ethanol blends (E25-E40), could offer significant benefits for the United States. These benefits include an improvement in vehicle fuel efficiency in vehicles designed and dedicated to use the increased octane. The improved efficiency of 5-10% could offset the lower energy density of the increased ethanol content, resulting in volumetric fuel economy parity of E25-E40 blends with E10. Most of the flex-fuel vehicles on the road today would be expected to have faster acceleration using HOF, which offers a marketing opportunity in the near term. Furthermore, dedicated HOF vehicles would provide lower well-to-wheel GHG emissions from a combination of improved vehicle efficiency and increased use of ethanol. If ethanol were produced using cellulosic sources, GHG emissions would be expected to be up 17 to 30% lower than those from E10 using conventional ethanol and gasoline. Refinery modeling suggests that refiners could use higher levels of ethanol to meet potentially high market shares of HOF. Analysis of the HOF market and the primary stakeholders reveals that the automotive OEMs, consumers, fuel retailers, and ethanol producers all stand to benefit to varying degrees as HOF increases its market share. The results depend on the underlying assumptions; but HOF offers an opportunity for improved fuel economy, and these dedicated vehicles are likely to be appealing to consumers. The possible limiting constraints to significant HOF market penetration were identified. Regulatory uncertainty and insufficient retailing investment were considered the most likely constraints to limit the introduction of HOF. HOF could be limited by the rate of construction of

additional integrated biorefinery capacity, and poor dedicated HOF vehicle penetration would also limit the overall HOF market. Feedstock availability was not found to limit the growth of HOF."
http://info.ornl.gov/sites/publications/Files/Pub61169.pdf

A Vehicle Manufacturer's Perspective on Higher-Octane Fuels (2014)
Authors: T.G. Leone (Ford)
A presentation by Tom Leone/Ford on how high octane is both a good idea and necessary to meet CO2 goals.
http://energy.gov/sites/prod/files/2014/11/f19/leone_biomass_2014.pdf

Well-to-Wheels Greenhouse Gas Emissions Analysis of High-Octane Fuels With Various Market Shares and Ethanol Blending Levels
Authors: J. Han, A. Elgowainy, M. Wang
"The overall WTW GHG emission changes associated with HOF vehicles were dominated by the positive impact associated with vehicle efficiency gains and ethanol blending levels, while the refining of gasoline blendstock for oxygenate blending (BOB) for various HOF blend levels (E10, E25, and E40) had a much smaller impact on WTW GHG emissions. The 5% and 10% MPGGE gains by HOF reduced the WTW GHG emissions by 4% and 8%, respectively, relative to baseline E10 gasoline. The additional WTW GHG reductions when corn ethanol was used for blending were 5% and 10% for E25 and E40, respectively. As a result, when corn ethanol was used, total WTW GHG emission reductions from using E10, E25, and E40 relative to baseline E10 gasoline were 5%, 10%, and 15%, respectively, with a 5% MPGGE gain, while using E40 achieved an 18% total WTW GHG emission reduction with a 10% MPGGE gain. When corn stover ethanol was used for blending, the additional WTW GHG reductions were 12% and 24% for E25 and E40, respectively. As a result, with the corn stover ethanol, total WTW GHG emission reductions from using E10, E25, and E40 relative to baseline E10 gasoline were 8%, 18%, and 28%, with a 5% MPGGE gain, while using E40 achieved a 32% total WTW GHG emission reduction, with a 10% MPGGE gain."
https://greet.es.anl.gov/files/high-octane-various-shares