Joint Comments on E15 Education and Outreach

January 29, 2019

To: U.S. Environmental Protection Agency
Office of Transportation and Air Quality
2000 Traverwood Drive
Ann Arbor, MI 48105

Re: Modifications to Fuel Regulations to Provide Flexibility for E15; RIN 2060-AU34

The Outdoor Power Equipment Institute (OPEI) and the National Marine Manufacturers Association (NMMA) appreciate the opportunity to provide background information on the need for EPA to strengthen its Misfueling Mitigation Program (MMP) at the same time the agency proposes to allow fuel containing 15 percent ethanol (E15) to be sold year-round.

OPEI is an international trade association representing the manufacturers and their suppliers of small engines, utility vehicles, personal transport vehicles, golf cars and consumer and commercial outdoor power equipment. These products are commonly found in most American households and include products such as lawnmowers, garden tractors, trimmers, edgers, chain saws, snow throwers, tillers, leaf blowers, generators, and power washers. While small engines and outdoor power equipment consume a small percentage of the nation's fuel supply, their ownership by the American consumer is ubiquitous. Additionally, many of these same products are made for commercial use by contractors, farmers, utility crews, parks and recreation, states and municipalities, and fire and emergency rescue personnel. Many of these products have long service lives which can exceed a decade, resulting in an estimated 250 million legacy products currently in use. Our industry contributes approximately $16 billion to annual U.S. GDP and employs some 150,000 people across 50 states.

NMMA is the leading recreational marine industry trade association in North America, representing 1,500 boat, engine, and accessory manufacturers. NMMA members collectively produce more than 80 percent of the recreational marine products sold in the

United States. Recreational boating is a significant driver of the country's economy, employing 691,000 people across more than 35,000 boating businesses, while contributing $170 billion in economic activity. What's more, 142 million recreational boaters take to the water annually in the U.S., consuming about 2.1 billion gallons of gasoline.

EPA's modifications to existing fuel regulations to allow E15 to be sold year-round are deeply concerning to the outdoor power equipment and recreational boating industries, due to the negative impact of higher-ethanol blend fuels on outdoor power equipment, marine engines and vessels, and consumers. E15 is not approved for use in these non-road engines[1] and EPA has established a Misfueling Mitigation Program (MMP) to reduce the likelihood of E15 blend fuels from being used in engines for which that fuel is not approved.[2] However, as OPEI and NMMA have each explained in detailed comments submitted to the agency on previous rulemakings, additional mechanisms are required to fully prevent misfueling of non-road engines. Without a more comprehensive misfueling mitigation program in place, expanding the availability of E15 will significantly increase the risk of damage to non-road engines. OPEI and NMMA therefore request that EPA include in its proposal measures to address the continued need for robust consumer education and outreach on E15 usage and impacts on non-road engines. These comments address the need for such additional education and outreach and also provide suggested preamble language that could be included in the agency's notice of proposed rulemaking.

Use of E15 and Higher Ethanol Blends Fuels in Non-Road Engines will Damage those Engines and Cause Harm to Manufacturers and Consumers

Use of E15 in non-road engines has both adverse environmental and economic consequences. The additional oxygen content of higher ethanol blend fuels produces a significant increase in engine temperatures that results in increased engine wear and ultimately engine failure. Further, the increased amount of ethanol causes increased corrosion of both metallic and rubber and plastic components. This in turn leads to

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[1] 75 Fed. Reg. 68,094 (Nov. 4, 2010).
[2] 40 C.F.R. Part 80, Subpart N—Additional Requirements for Gasoline-Ethanol Blends.

performance degradation, emission increases, engine failure, and potential fuel leaks as rubber and plastic components no longer form a complete seal. Based on studies conducted in conjunction with the U.S. Department of Energy, use of E15 in marine engines results in emissions increases outside of EPA certification limits, increased fuel consumption, and damage severe enough to prevent engines from completing the EPA durability testing process.[3] Testing conducted on small non-road engines also identified problems related to E15 use, including leaner engine operation, higher operating temperatures, higher operating speed, and unintentional clutch engagement.[4] Based on these studies and others, EPA has prohibited the use of E15 in small off-road engines, such as those used in lawnmowers, tractors, utility vehicles, trimmers, chain saws, and other lawn and garden equipment. EPA also prohibited the use of E15 in marine engines and other non-road equipment.[5] Attached to these comments are additional materials previously provided to EPA regarding the effects of E15 and other ethanol blends on non-road engines. Increasing the availability of E15 likewise increases the risk that consumers will choose the wrong fuel for use in their non-road products, increasing the economic and environmental harms from misfueling of non-road engines. For marine engines, the potential for engine failure due to use of E15 presents the additional safety risk of leaving boaters stranded on the water.

Recent Polling Data Suggests that Widespread Consumer Confusion Continues Regarding the Use of E15 and other Ethanol Blends in Non-Road Engines.

Even though EPA has prohibited the use of E15 in non-road engines, misfueling continues and consumers remain confused about the fuels that are appropriate for use in their non-road and marine engines. A Harris Poll conducted in 2018 on behalf of OPEI concluded that more consumers are using the wrong type of fuel in their products. In 2018, 11% of those surveyed reported using E15, E30, E50, or E85 to fuel their equipment, up from 7% in 2015. The study found that Americans are more likely now

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[3] http://www.nmma.org/assets/cabinets/Cabinet515/Marine%20Biobutanol%20Research%20Book%20SFS2.compressed.pdf

[4] *See, e.g.*, Comments of Dr. Ron Sahu on "Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated," NREL/TP-540-43543 and ORNL/TM-2008/117, Feb. 2009

[5] See 75 Fed. Reg. 68,094.

than in years past to believe higher ethanol blends of gasoline are safe for any gasoline (i.e., non-diesel) engine (38% in 2018 vs. 31% in 2017, 31% in 2016, and 30% in 2015). The Harris Poll also found that only 20% of consumers, down from 25% in 2017, say they notice the ethanol content at a gas pump. When asked about the label required under the current EPA MMP, more than 3 in 5 Americans (63%) feel it is inadequate to inform consumers about E15 fuel being illegal to use in outdoor power equipment.

Outdoor power equipment products are also unique because they are often fueled from portable containers, which are typically fueled at the same time and location as the vehicle used to transport the container from the filling station to the off-road equipment location. In fact, many types of non-road products, including lawn, garden, and forestry products and off-road vehicles like ATVs and utility vehicles, are exclusively refueled from portable containers. Portable fuel containers have a range of opening sizes for refilling the container and any fuel dispensing nozzle that could be utilized to fill a vehicle can also be used to fill the portable container. Current pump labels may be effective in preventing misfueling of vehicles at the time of fueling, but may not clearly communicate the risk of using that same fuel to fill a portable container that will later be used to refuel nonroad equipment.

The fueling of boats also presents unique challenges. Approximately 95% of recreational boats are less than 26 feet in length and are capable of being—and often are—transported by trailer to water bodies. The vast majority of these boats are fueled at retail gas stations when being towed behind vehicles, rather than fueled at marinas. The risk of misfueling with E15 is therefore high, particularly if fuel pumps are not clearly labeled regarding ethanol content or effectively warn customers that E15 should not be used in marine engines.

The images in Attachment 1 [6]show examples of current pump configurations and labeling. The sheer number of labels on these fuel pumps makes the ethanol content and warning labels difficult to locate and even more difficult to comprehend, particularly in

[6] https://spaces.hightail.com/space/dqYb9hZhQf

the few seconds consumers may spend deciding on the grade or type of fuel to purchase. As these photos show, label location also differs from pump to pump, so consumers cannot always expect to look to a standard location on the fuel pump to determine the ethanol content of a fuel before making purchasing decisions. Even if the current E15 warning label alone were sufficient to deter misfueling, the lack of standardized label placement and frequent placement above or below eye level or behind hoses significantly reduces its effectiveness. The photos in Attachment 1 also depict the advertisement of "Unleaded 88" fuel, which contains 15 percent ethanol but is labeled to appear to be an 88 octane gasoline. Although pumps dispensing "Unleaded 88" also carry the current E15 warning label, the signage and display of the fuel is confusing and misleading to customers. These changes in fuel marketing strategies and continuing consumer confusion about appropriate fuels for their vehicles and engines merit careful review by EPA and the establishment of a more robust misfueling mitigation program.

Industry Efforts to Educate Consumers about Fuel Choices are Effective but Must Be Supplemented with EPA Action and a Stronger Misfueling Prevention Program

In 2013, OPEI, in partnership with NMMA, launched a "Look Before You Pump" program. Both organizations have used "Look Before You Pump" materials and messaging with local and national dealers, service, and retails outlets to communicate the importance of using only approved fuels in non-road engines. NMMA has also partnered with boating safety and certification organizations, state boating associations, and national groups like BoatUS and the American Sportfishing Association to increase awareness about the need to use E0 or E10 fuel in marine engines. OPEI and NMMA have worked diligently for five years to raise awareness among outdoor power equipment and marine engine manufacturers, dealers, retail outlets, and owners about proper fueling. Despite this lengthy and concerted campaign, the polling data cited above demonstrates that industry efforts and the current EPA MMP are not sufficient to ensure that consumers are fully aware of the risks of fueling their non-road products with E15.

EPA also has a legal obligation to prevent use of E15 in engines for which the fuel is not approved. Under section 211(f) of the Clean Air Act (CAA), EPA may only waive the prohibition against the introduction into commerce of any fuel after the agency concludes that the fuel or fuel additive will not cause or contribute to engines or equipment failing to meet applicable emission standards over their useful life. Further, CAA section 211(c)(1) allows EPA to control the introduction into commerce, offering for sale, or sale of any fuel or fuel additive if such fuel or fuel additive, or any emission product of such fuel or fuel additive, causes or contributes to air pollution that endangers public health or welfare, or will impair the performance of an emission control device or system that is in general use. It is under these two provisions that EPA first issued the original MMP.[7] The same two provisions obligate EPA to consider whether additional controls on the sale, or offering for sale, of E15 are necessary to ensure that use of the fuel does not cause or contribute to air pollution or impair the performance of emission control systems. Based on the polling data summarized above and provided in full in Attachment 2, the current MMP and industry stakeholder efforts are insufficient to mitigate against misfueling to the fullest extent practicable. Therefore, EPA must develop a broad outreach effort to increase consumer knowledge of the economic harm and environmental impacts that can result from use of E15 in outdoor power equipment and marine engines.

Misfueling of Marine and Outdoor Power Equipment Engines Causes Economic Harm to Consumers

The polling cited above found that consumers are increasingly using fuels with more than 10 percent ethanol to fuel their marine engines and outdoor power equipment. The result of misfueling is engines that perform poorly, or not at all, and which can pose safety risks to the user. An engine destroyed by use of E15 means that industries and individuals who rely on lawn and garden equipment, chain saws, snow blowers, and tillers may have equipment out of service; contractors, farmers, utility crews, parks and recreation departments, landscapers, states and municipalities, and fire crews may be unable to work if their equipment is not functioning. Because misfueling voids the manufacturer's warranty, the cost of replacing equipment damaged by E15 is entirely borne by the consumer. Many of these products can have service lives of up to 10 years or more if properly maintained but the cost of early replacement due to misfueling can have

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[7] 75 Fed. Reg. 44,406, 44,410 (July 25, 2011).

significant economic consequences to individual consumers and to industries that rely on outdoor power equipment to perform their functions.

In the boating industry, approximately 64% of boat owners have annual household incomes below $100,000. Replacing an engine that is damaged by E15 use can cost the consumer several hundred to several thousand dollars. Again, use of E15 voids the manufacturer's warranty so the entire cost of misfueling is shouldered by the consumer.

If E15 is permitted to be sold year-round, the rate of misfueling is likely to increase, along with the economic impact on the public. The economic costs of misfueling, and the need to protect consumers from the expense of replacing engines and equipment damaged by E15 use, weigh heavily in favor of a more comprehensive misfueling mitigation plan and increased customer awareness of the risks of E15 use. A coordinated effort by *all* stakeholders—including EPA—to educate consumers about the need to carefully select the fuel used in marine engines and outdoor power equipment is required.

Specific Recommendations for Reducing Misfueling and Improving Consumer Awareness about E15

First, EPA should request comment on whether changes should be made to the E15 label currently in use on fuel pumps dispensing that fuel. Specifically, NMMA and OPEI recommend that EPA request comment on whether the size, design, or other characteristics of the label should be changed to more clearly communicate the fuel's ethanol content to consumers. NMMA and OPEI also recommend that EPA request comments on the placement of labels in order to maximize the effectiveness of the label and increase consumer awareness of the fuel's ethanol content. EPA should also request comments on whether E15 pump labels should carry warnings in languages other than English in order to more broadly communicate the risk of fueling nonroad engines with E15. Additionally, EPA should also seek comment on whether specific changes are necessary to the labels used on E85, blender pumps, and pumps dispensing midlevel ethanol blend fuels, as well as labels for pumps dispensing E0 and E10 fuels.

Second, EPA should request comment on whether to require physical barriers to be implemented that would reduce the risk of misfueling of engines for which the use of E15 is not approved. Specifically, NMMA and OPEI recommend that EPA request comment on whether to require fuel pumps dispensing E15 or higher-ethanol blends to be equipped with a key pad approval system that would be tied to payment method or fuel grade selection. A keypad system is NMMA and OPEI's preferred approach to a physical barrier to prevent misfueling. This system could require the consumer to confirm that she or he understands that the fuel contains more than 10% ethanol and cannot be legally used in non-road products due to the risk of substantial damage and/or voiding warranty coverage. In the 2011 MMP, EPA concluded that information available at that time did not support the adoption of a keypad or touch screen information display or confirmation requirement. However, due to the expanded availability of E15 and the likely increase in sale of E15 due to the recent RVO increases, this option is likely to be more cost-effective and feasible than when E15 volumes were significantly lower. OPEI and NMMA therefore recommend that EPA request comments on the potential cost of implementing such systems as well as the effectiveness in preventing misfueling of non-road engines. We recognize that implementing a keypad verification system imposes costs on fuel retailers. However, engine damage and replacement imposes significant costs on consumers that can be avoided if robust barriers are put in place to prevent misfueling in the first place.

NMMA and OPEI also recommend that EPA request comments on whether to consider adopting a different fuel pump nozzle size for those pumps dispensing E15. EPA previously rejected a different-sized nozzle as not feasible.[8] However, at the time of the original MMP, EPA anticipated that the transition to E15 would take time and would not immediately be available across the country.[9] Considering the current broad availability of E15 and the agency's intent to allow E15 to be sold year-round, EPA must reconsider whether physical barriers to use of E15 in engines for which use of that fuel is not approved would now be a more cost-effective solution to preventing misfueling. NMMA

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[8] *See* 75 Fed. Reg. at 44, 426.
[9] *Id.*

and OPEI recognize that requiring different-sized nozzles for E15 comes at a cost to fuel retailers. However, we strongly recommend that EPA balance the cost of implementing physical barriers to misfueling with the costs to consumers of replacing marine engines and outdoor power equipment due to damage from misfueling. The economic impact on fuel retailers alone should not be the only factor in determining whether physical barriers are a feasible option.

In addition, NMMA and OPEI recommend that EPA consider whether to require dedicated fuel pumps dispensing only fuels containing 10 percent or less ethanol. We believe that this is the only option that will completely mitigate against misfueling. Beyond the new products being sold each day, OPEI also estimates as many as 250 million legacy products owned by U.S. households and businesses, all of which require gasoline with no more than 10% ethanol to run properly and safely. It is also important to note that many of the commercial-grade and higher price point products manufactured by our members will likely be in service for decades to come. Similarly, recreational boats are designed and built to be used for decades. While newer marine engines are designed to operate on E10, approximately 16 million legacy marine engines remain in use that will be harmed by higher-ethanol blends. We therefore recommend that EPA propose to require the continued sale of E10 and E0 fuels, as well as require fuel retailers to maintain a dedicated pump for E0 or E10 gasoline.

Finally, NMMA and OPEI also recommend that EPA seek comment on other misfueling mitigation strategies that were deemed to have benefits outweighed by cost in the 2011 MMP final rule. Among these options were distinctive fuel pump hand warmers for E15 dispensers and RFID technologies.[10] OPEI and NMMA recommend that EPA also request comment on any other measures that would reduce the risk of misfueling and increase customer awareness of the harm E15 poses to non-road engines.

Proposed Preamble Language on Consumer Education and Pump Labeling Requirements

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[10] 75 Fed. Reg. at 44,426-427.

Joint Comments on E15 Education and Outreach

NMMA and OPEI respectfully provide the sample preamble language that could be included in EPA's notice of proposed rulemaking to explain the rationale for revising the MMP and solicit comment on what measures would be effective in increasing customer awareness of the risks of misfueling.

> In 2010 and 2011, EPA determined that the use of E15 in some small engines will damage those engines and equipment.[11] EPA denied the E15 waiver request for non-road engines, vehicles, and equipment on the basis that "there are emission related concerns with the use of E-15 in non-road products, particularly regarding long-term exhaust and evaporative emission (durability) impacts and material compatibility issues."[12]
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> Following the partial waiver prohibiting the use of E15 in these types of engines and equipment, EPA issued a misfueling mitigation rule.[13] In this rule, EPA recognized its concerns with misfueling E15 into non-road products "include the potential for elevated exhaust and evaporative emissions, as well as the potential for emissions impacts related to engine failure from overheating."[14] We concluded that these emission related problems could potentially occur with enough frequency that the avoided emissions increases from reduced or prevented misfueling would more than outweigh the relatively low cost imposed by the required misfueling mitigation regulations.[15] Therefore, the potential emission increases from misfueling supported the establishment of the original misfueling mitigation plan, even though a very low percentage of engines and products might experience misfueling or an increase in emissions.
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> At the time of the MMP, we anticipated that the introduction of E15 into the marketplace would likely start in a limited number of areas and grow over time before becoming broadly available. We also recognized that a public outreach

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[11] 75 Fed. Reg. 68,094 (Nov. 4, 2010); 76 Fed. Reg. 4662 (Jan. 26, 2011).
[12] 75 Fed. Reg. 68,094, 68,137.
[13] 76 Fed. Reg. 44,406 (July 25, 2011).
[14] 76 Fed. Reg. at 44,409..
[15] *Id.*

campaign, in partnership with stakeholders, would be crucial to understanding how E15 would be distributed, sold, and used, and would provide a forum for identifying and resolving issues that developed as E15 moved into the marketplace.

Now that we are proposing to allow the sale of E15 year-round, EPA requests comments on whether EPA should adopt a more robust set of consumer education and pump labeling requirements. Effective outreach to consumers is essential to the successful extension of the year-round availability of E15 without increasing misfueling of those engines and equipment for which E15 use is not approved. Outreach to consumers is critical to help mitigate misfueling incidents that can result in increased emissions or vehicle or engine damage.

EPA recognizes concerns raised by industry stakeholders that the current misfueling mitigation plan may not be adequate to prevent misfueling of all engines for which the use of E15 is not approved. A Harris Poll conducted in 2018 on behalf of industry stakeholders concluded that misfueling of nonroad engines is increasing, rather than decreasing. According to stakeholder polling data, in 2018, 11% of those surveyed reported using E15, E30, E50, or E85 to fuel their equipment, up from 7% in 2015. The study found that Americans are more likely now than in years past to believe higher ethanol blends of gasoline are safe for any gasoline (i.e., non-diesel) engine (38% in 2018 vs. 31% in 2017, 31% in 2016, and 30% in 2015). The Harris Poll also found that only 20% of consumers, down from 25% in 2017, say they notice the ethanol content at a gas pump. When asked about the label required under the current EPA MMP, more than 3 in 5 Americans (63%) feel it is inadequate to inform consumers about E15 fuel being illegal to use in outdoor power equipment.

Because the use of a non-approved fuel voids the manufacturer's warranty, the cost of misfueling of marine engines and outdoor power equipment is primarily borne by the public. Beyond the cost of replacing engines that are damaged or destroyed by E15, misfueling can have broader economic impacts. Outdoor power equipment, including lawn mowers, tractors, chain saws, and generators are used by a variety of industries, including landscapers, farmers, contractors, parks and recreation departments, and fire crews. Inoperable equipment may mean that individuals and companies may be temporarily out of work or unable to perform certain jobs. Marine engines damaged by E15 also are not covered by the manufacturer's warranty, so the consumer bears the cost of replacement. Because of these economic impacts, EPA believes that amending the current MMP is required.

First, EPA requests comment on whether changes should be made to the E15 label currently in use on fuel pumps dispensing that fuel. Specifically, EPA requests comment on whether the size, design, or other characteristics of the label should be changed to more clearly communicate the fuel's ethanol content to consumers. EPA also requests comments on the placement of labels in order to maximize the effectiveness of the label and increase consumer awareness of the fuel's ethanol content. EPA also requests comments on whether E15 pump labels should carry warnings in languages other than English in order to more broadly communicate the risk of fueling nonroad engines with E15.

In addition to labels on E15 pumps, EPA also seeks comment on whether E85, blender pumps, and mid-level ethanol blend pumps should have labels indicating that such fuels should not be used in nonroad engines. As with the E15 label, EPA seeks comment on the size, design, language, placement on pumps, and other characteristics of the label that would clearly communicate the fuel's ethanol content and the engines in which the fuel is authorized for use.

Second, EPA requests comment on whether we should require physical barriers to be implemented that would reduce the risk of misfueling of engines for which the use of E15 is not approved. Specifically, EPA requests comment on whether we should require fuel pumps dispensing E15 or higher-ethanol blends to be equipped with a key pad approval system that would be tied to payment method or fuel grade selection. This system could require the consumer to confirm that she or he understands that the fuel contains more than 10% ethanol and cannot be legally used in non-road products due to the risk of substantial damage and/or voiding warranty coverage. EPA requests comment on the potential cost of implementing such systems as well as the effectiveness in preventing misfueling of non-road engines.

In addition, EPA requests comments on whether we should consider adopting a different fuel pump nozzle size for those pumps dispensing E15. In the past, EPA concluded that requiring a different nozzle size for pumps dispensing E15 was not a cost-effective method of preventing misfueling in light of the relatively slow and region-by-region adoption of E15 fuels. We seek comment on whether the year-round availability of E15 will significantly increase the risk of misfueling to the point that implementing differently-sized fuel pump nozzles would now be a cost-effective method of preventing misfueling.

Third, EPA requests comment on the type of public outreach and consumer education program, beyond fuel pump labeling and physical barriers, that would be effective in mitigating misfueling. EPA also requests comments on the appropriate stakeholders that should be involved in the development of this agency-led outreach effort. In the context of this program, potential key stakeholders include ethanol producers, fuel manufacturers, automobile, engine and equipment manufacturers, States, non- governmental organizations, parties in the fuel distribution system, EPA, DOE, and USDA. EPA requests comment on potential education and outreach activities a public/private group could undertake, include serving as a central clearinghouse for technical questions about E15 and its use, promoting best practices to educate consumers or mitigate misfueling instances, and developing educational materials and making them available to the public.

Joint Comments on E15 Education and Outreach

> In comments on EPA's MMP, some stakeholders suggested that a Web site be created to inform consumers of the potential impacts of E15 on older motor vehicles, heavy-duty gasoline engines and vehicles, motorcycles, and nonroad products. Stakeholders have further suggested that, if a unique misfueling Web site is created, then EPA should require the Web site address to be displayed on the E15, E85, and midlevel ethanol blend pump labels. EPA seeks comment on the appropriateness of a unique misfueling Web site and of including such a Web site address on these labels. Many of these efforts have already been taken by industry stakeholders. EPA seeks comment on how current industry efforts can be adapted to further the agency's goal of reducing misfueling.
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> Finally, EPA requests comment on whether to mandate the continued availability of fuels containing 10 percent or less ethanol. We also seek comment on whether to require fuel retailers to maintain a dedicated fuel pump to dispense E10 or E0 gasoline.
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> We also seek comment on any other measures not proposed in the rule that the regulated industries and other interested parties feel may be necessary to mitigate misfueling. We seek comment on any other cost-effective mitigation measures that may be appropriate. If EPA considers requiring any other mitigation measures that are suggested by commenters in the final rule, EPA will conduct appropriate analyses of such measures, including the impacts on small businesses, before deciding whether to include such mitigation measures in the final rule.

Conclusion

OPEI and NMMA appreciate the opportunity to provide the foregoing comments and background information to inform EPA's proposal to allow E15 to be sold year-round. Attached to these comments is additional background information regarding the effects of E15 on outdoor power equipment and marine engines. Please contact Dan Mustico at dmustico@opei.org or 703- 678-2990 or Nicole Vasilaros at nvasilaros@nmma.org or 202-737-9763 with any questions.

Sincerely,

Dan Mustico
Vice President, Government and Market Affairs
Outdoor Power Equipment Institute

Nicole Vasilaros
SVP, Government and Legal Affairs
National Marine Manufacturers Association

ATTACHMENT 1


ATTENTION
E15
Up to 15% ethanol
Use only in
• 2001 and newer passenger vehicles
• Flex-fuel vehicles
Don't use in other vehicles, boats, or gasoline-powered equipment. It may cause damage and is prohibited by Federal law.
Insert Card


3
87
88
93


85
ethanol
FLEX-FUEL
Push Here
88


E85
REGULAR
WARNING
WARNING
E85
88


ATTENTION
E15
Use only in


E-15
ETHANOL
UNLEADED
UNLEADED
87
88
93
Diesel

CONTAINS UP TO 10% ETHANOL
CONTAINS UP TO 15% ETHANOL
$ 2.849
$ 2.649
PRICE PER GALLON, ALL TAXES INCLUDED
UNLEADED
UNLEADED 88
MINIMUM OCTANE RATING (R+M) / 2 METHOD
87
88

$
Gallons
59.42
20.080
Insert Card
85
UNLEADED
88
87
89
92

10% ETHANOL
CONTAINS UP TO 10% ETHANOL
FOR USE IN:
• Gasoline powered vehicles.
• Most late model outdoor power equipment. Check your owners manual for verification.
ATTENTION
E15
Use only in
•Flex-fuel vehicles
87
88

$
Gallons
59.42
20.080
85
UNLEADED
Insert Card

CONTAINS UP TO 10% ETHANOL
E15
88

Gravin's
Premium
Chocolate Bars
2 for $3
88
87
89
93

ATTACHMENT 2

Look Before You Pump Survey Results

March 2, 2018

Prepared For:

OUTDOOR POWER EQUIPMENT INSTITUTE

Prepared By:

Harris On Demand
The Harris Poll

Research Method and Note about the Report

Research Method

The surveys were conducted online within the United States by Harris Poll on behalf of Outdoor Power Equipment Institute among US adults ages 18+. The 2018 survey was conducted between February 20-22, 2018 among 2,027 adults. The 2017 survey was conducted between February 27 and March 1, 2017 among 2,186 adults. The 2016 survey was conducted between March 11-15, 2016 among 2,023 adults. The 2015 survey was conducted between April 23-27, 2015 among 2,015 adults.

Results were weighted for age within gender, region, race/ethnicity, income, and education where necessary to align them with their actual proportions in the population. Propensity score weighting was also used to adjust for respondents' propensity to be online.

All sample surveys and polls, whether or not they use probability sampling, are subject to multiple sources of error which are most often not possible to quantify or estimate, including sampling error, coverage error, error associated with nonresponse, error associated with question wording and response options, and post-survey weighting and adjustments. Therefore, Harris Poll avoids the words "margin of error" as they are misleading. All that can be calculated are different possible sampling errors with different probabilities for pure, unweighted, random samples with 100% response rates. These are only theoretical because no published polls come close to this ideal.

Respondents for this survey were selected from among those who have agreed to participate in online surveys. The data have been weighted to reflect the composition of the adult population. Because the sample is based on those who agreed to participate in our panel, no estimates of theoretical sampling error can be calculated.

A Note about Reading the Report

The percentage of respondents has been included for each item.

- An asterisk (*) signifies a value of less than one-half percent.
- A dash represents a value of zero.
- Percentages may not always add up to 100% because of computer rounding or the acceptance of multiple responses.

How to Read Data Tables: Key Terms & Statistical Significance Testing

Tabs or Cross-tab(s): This is short for cross-tabulations, or data tables. Raw survey data are tabulated to depict the results based on aggregate groups of respondents, typically, the "Total" sample, as well as subgroups that can be compared against one another to see if there are statistically significant differences among them (e.g., men vs. women).

Banner: A banner is essentially a set of cross-tabs.

Banner point: A banner point is a column in the data tables – a single banner, or page of cross-tabs, can typically include about 20 columns, or banner points (depends partly on the banner point titles/labels). Banner points enable us to compare two or more groups to one another to see if there are statistically significant differences among them (e.g., the data for "men" would be contained in one banner point and "women" in another, with the two columns stat-tested against one another to determine if the differences are statistically significant).

Statistical significance testing: Two or more banner points can be tested for significant differences based on a statistical formula called a t-test – whether or not a difference between 2 or more groups is significant depends not only on the magnitude of the difference, but also on the sizes of the samples being compared (i.e., the smaller the samples, the larger a difference would have to be in order to be considered statistically significant).

Significance testing is done at the 95% confidence level, and the test is performed on percentages as well as means. Each subgroup is contained in a banner point and assigned a letter. When the percentage of one subgroup is significantly different from the percentage of another subgroup, the letter representing one of the two samples appears next to the percentage (or mean) of the other sample.

For example, the proportion of males answering "yes" to a particular question may be compared to the percentage of females answering "yes" to the same question, as follows:

- In the table below, the male sample is assigned the letter B and the female sample is assigned the letter C.
- 67% of women said "yes" – a proportion that is significantly greater than the 57% of males who said "yes."
- To indicate that women are significantly more likely to say "yes" than are men, the letter B (i.e., the letter assigned to the male subgroup) appears next to the "67%" in the female column.
- Similarly, the 37% of men who said "no" is significantly greater than the 29% of women who said "no," so the letter C (i.e., the letter assigned to the female subgroup) appears next to the "37%" in the male column.
- It is these letters that indicate statistically significant differences among two or more subgroups – if there are no letters next to a percentage, then the differences are not statistically significant and may not be described as true differences in attitude or behavior among subgroups.

		Gender	
	Total	Male	Female
	(A)	**(B)**	**(C)**
Unweighted Total	977	488	489
Weighted Total	967	464	503
Yes	611	274	337
	63%	57%	67%**B**
No	319	171	148
	33%	37%**C**	29%
Don't Know	37	18	19
	4%	4%	4%

Key Findings

Ethanol Awareness

Most Americans are aware that there is ethanol in gasoline, however, many do not seem to know that gasoline with a high ethanol content (higher than 10 percent) is currently available at gas stations. While more than 4 in 5 Americans (84%) know that gasoline contains ethanol, more than 2 in 5 (41%) admit they are not aware that higher ethanol blends of gasoline are currently available at gas stations. Perhaps this can be attributed to lack of media attention on the subject, or at least memorable attention - nearly two thirds of Americans (64%) did not see, hear or read anything in the news regarding levels of ethanol at fuel pumps at gas stations in the past 12 months (up from 58% in 2015) and about 1 in 5 (18%) are not sure if they did.

Ethanol Misconceptions

Many Americans do not realize that higher blends of ethanol gasoline are not safe and illegal to use in some engines. Only a third of Americans (33%) think higher ethanol blends of gasoline are harmful to engines such as those in boats, mowers, chain saws, snow mobiles, generators, and other engine products. On the flip side, nearly 2 in 5 Americans (38%) believe this type of gasoline is safe to use for any gasoline engine – this number jumps to 42% among men. This misconception is at its highest since 2015 - Americans are more likely in 2018 than in the past 3 years to believe higher ethanol blends of gasoline are safe to use for any gasoline engine (38% vs. 31% in 2017, 31% in 2016, and 30% in 2015). Perhaps this lack of knowledge is due to many blindly trusting that gas stations wouldn't sell fuel that isn't safe. Nearly two thirds of Americans (65%) assume that any gas sold at the gas station is safe for all cars, as well as boats, mowers, chain saws, snow mobiles, generators and other engine products.

Shockingly, one in five Americans (20%) think it is legal to put gasoline with an ethanol content higher than 10 percent into engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products – this jumps to 30% among men – and the majority of Americans (68%) are not at all sure if it is legal. This ignorance may not be at the fault of the consumer, however, as the EPA has put out a non-mandatory label, 2.5 x 2.5 inch, for gas stations to post if they sell fuel greater than E10. When asked about the current voluntary warning label to inform consumers about E15 fuel being illegal to use in outdoor power equipment, more than 3 in 5 Americans (63%) feel it is inadequate – with women being more likely than men to feel this way (67% vs. 59%).

Bad Behavior at the Pump

While many Americans notice items specific to payment at a gas pump, like price (85%) and if a pump accepts credit cards (57%), far fewer notice the ethanol content. Only 1 in 5 Americans (20%, down from 25% in 2017) say they notice the ethanol content when at a gas pump, with more saying they notice advertisements for specials available inside (24%). Which begs the question, are less people paying attention to ethanol content because they just don't see it, or because they are not aware how it could impact their fueling?

It appears it could be a little bit of both, based on current misconceptions and Americans' habits at the fuel pump. Just over 2 in 5 Americans (41%) admit they do not check the fuel pump for any warning labels when they fuel up their car, and more than one third (36%) do not always read the labels on the fuel pumps. Furthermore, about 3 in 5 Americans (59%) say they typically only pay attention to labels on fuel pumps that read "Warning" or "Do Not Use In..." – this number jumps to 67% among adults ages 18-34.

With all of that in mind, it's no surprise that many Americans are likely fueling incorrectly. Roughly two thirds (66%) admit they will use the least expensive grade of gasoline whenever possible and more than half (51%) fill up their portable gas tank with the same fuel used to fill their vehicle.

Mis-Fueling Outdoor Power Equipment

While attention to fuel types has gone up since 2015 (43% in 2018 vs. 35% in 2015), outdoor power equipment owners are still making mistakes when it comes to their equipment. Among the 63% of Americans who own outdoor power equipment, less than half (43%) say they pay attention to the type of fuel they put into their equipment and just over one third (35%) don't know what type of fuel they are using. Additionally, about 1 in 10 Americans who own outdoor power equipment are mis-fueling – 11% of Americans say they have used E15, E30, E50, or E85 to fuel their equipment, up from 7% in 2015. Perhaps this misuse of higher ethanol blends of gasoline could be attributed to the fact that while it is more widely available, there is inadequate information at fuel pumps on when it is not safe to use them. While there is a clear need for more adequate labeling, there is also a need for more availability of safe fuel to use in engines other than cars - roughly two thirds of Americans (66%) feel ethanol-free gas should be more widely available at gas stations.

Caring For Outdoor Power Equipment

Most Americans who own outdoor power equipment appear to be confident in their gasoline storage habits – more than 4 in 5 (84%) say they always use a safe container when they store gasoline for their outdoor power equipment. However, the proper safety methods seem to end there. More than one third of Americans who own outdoor power equipment (35%) may be using stale fuel in their equipment as they admit to not running the tank dry/draining the fuel out of their equipment before storing it. Additionally, less than one third of Americans who own outdoor power equipment (29%) label the gasoline storage container they use for their outdoor power equipment with the date they purchased the fuel. This lack of labeling suggests that most don't understand the impacts of using old fuel. To further support that, over half of Americans who own outdoor power equipment (53%) would put fuel that is more than 30 days old in their equipment.

'Look Before You Pump' May Make an Impact at the Pump

Based on survey results, the 'Look Before You Pump' campaign's strong potential to impact Americans' actions at the pump remains strong. If they saw the 'Look Before You Pump' image nearly 9 in 10 Americans (89% in 2018 and 87% in 2017) claim they would be likely to make sure they are fueling correctly, while about 4 in 5 (81% in 2018 and 80% in 2017) would be likely to pay more attention to fuel types when putting gas in a jerry can/gasoline can. The impact on outdoor power equipment owners has increased this year – 86% say if they saw that image, they would be likely to pay more attention to fuel types when they put gas in their outdoor power equipment, compared to 82% last year. Additionally, the image has the potential to create other positive behaviors. Roughly two thirds of Americans would be likely to research different types of fuels (64%) or change the type of fuel they use (64%) if they saw the "Look Before You Pump" image

Key Findings

Notable Differences in Data Year Over Year

- Americans are more likely in 2018 than in 2016 and 2015 to say that they assume that any gas sold at the gas station is safe for all of their cars as well as boats, mowers, chain saws, snow mobiles, generators and other engine products. (65% vs. 60% and 57%, respectively).

- When arriving at the fuel pump at a gas station, there are some differences in what Americans notice on the pump year over year:

    - Less likely in 2018 than in 2017 to notice the ethanol content (20% vs. 25%)

- Americans are more likely in 2018 than in 2016 and 2015 to always read the labels on fuel pumps (58% vs. 53% and 50%, respectively).

- Americans are more likely in 2018 than in 2015 to say when they fuel up their car at the gas station, they check the fuel pump for any warning labels (53% vs. 47%, respectively).

- Americans are more likely in 2018 than in the past 3 years to believe higher ethanol blends of gasoline are safe to use for any gasoline engine (38% vs. 31% in 2017 and 2016, and 30% in 2015).

- Americans are more likely in 2018 than in 2016 and 2015 to think it is legal to put high level ethanol gas into engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products (20% vs. 15% and 16%, respectively).

- In terms of equipment maintenance, there are also some differences year to year in how Americans who own outdoor power equipment take care of their engines:

    - More likely in 2018 to pay attention to the type of fuel they use in outdoor power equipment than in 2016 and 2015 (43% vs. 36% and 35%, respectively)
    - More likely in 2018 than in 2015 to say they use E15/E30/E50/E85 in their outdoor power equipment (11% vs. 7%)
    - Less likely in 2018 than 2016 and 2015 to be unsure of what fuel they use in their outdoor equipment (35% vs. 42% and 45%, respectively)
    - More likely in 2018 than in 2016 to place equipment into long-term storage without draining the fuel tank (35% vs. 28%)
    - More likely to use diesel fuel in a non-diesel engine in 2018 than in 2016 (5% vs. 3%)
    - More likely in 2018 than in 2017 to not label gasoline storage containers used for their outdoor power equipment with the date they purchased fuel (57% vs. 49%)
    - More likely in 2018 than in 2017 to say if they saw the “Look Before You Pump” image, they would be likely to pay more attention to fuel types when they put gas in their outdoor power equipment (86% vs. 82%)

significant at 95% confidence level

Topline Data

BASE: U.S. RESPONDENTS
Q5 When you arrive at the fuel pump in a gas station, which of the following things do you notice on the pump? Please select all that apply.

BASE: All Respondents	**2018 (A)**	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*2,027*	*2,186*	*2,023*	*2,015*
EVER DRIVE/USE A FUEL PUMP (NET)	**96%BD**	**92%**	**94%**	**93%**
Price	85%	83%	86%**B**	86%**B**
If the pump accepts credit card payment	57%**C**	53%	52%	55%
Octane rating (e.g., 87 regular, 91 premium)	54%**D**	53%**D**	53%**D**	48%
Advertised specials available inside (e.g., beverages, food)	24%**C**	21%	19%	23%**C**
Ethanol content	20%	25%**A**	23%	23%
Other	2%	4%**A**	3%	3%
N/A – I don't ever drive/use a fuel pump.	4%	8%**A**	6%	7%**A**

BASE: Ever Drive/Use A Fuel Pump	**2018 (A)**	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*1,928*	*2,034*	*1,893*	*1,852*
Price	89%	89%	92%**A**	93%**AB**
If the pump accepts credit card payment	60%**C**	57%	55%	59%
Octane rating (e.g., 87 regular, 91 premium)	57%**D**	58%**D**	56%	52%
Advertised specials available inside (e.g., beverages, food)	25%**C**	23%	20%	25%**C**
Ethanol content	21%	27%**A**	24%	25%
Other	2%	5%**A**	4%**A**	4%**A**

BASE: U.S. RESPONDENTS
Q10 Do you know that there is ethanol in gasoline?

	2018 (A)	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*2,027*	*2,186*	*2,023*	*2,015*
Yes	84%	84%	85%	84%
No	16%	16%	15%	16%

BASE: U.S. RESPONDENTS
Q15 Do you recall seeing, hearing or reading anything in the news regarding levels of ethanol at fuel pumps at gas stations in the past 12 months?

	2018 (A)	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*2,027*	*2,186*	*2,023*	*2,015*
Yes	19%	18%	19%	22%**BC**
No	64%**D**	64%**D**	63%**D**	58%
Not sure	18%	18%	18%	20%

BASE: U.S. RESPONDENTS

Q20 How strongly do you agree or disagree with the following statement? “I have become aware within the last 2 years that higher ethanol blends of gasoline are available at fuel pumps at gas stations”

	2018 (A)	2017 (B)	2016 (C)	2015 (D)
n=	*2,027*	*2,186*	*2,023*	*2,015*
ALREADY AWARE/HAVE BECOME AWARE WITHIN LAST 2 Years (NET)	**59%**	**59%**	**59%**	**61%**
I was already aware that higher ethanol blends of gasoline are available at fuel pumps at gas stations.	19%	24%**A**	26%**A**	26%**A**
STRONGLY/SOMEWHAT AGREE (SUBNET)	**39%BCD**	**35%**	**33%**	**35%**
Strongly agree	8%**C**	8%**C**	5%	7%**C**
Somewhat agree	31%**B**	27%	28%	29%
STRONGLY/SOMEWHAT DISAGREE (SUBNET)	**41%**	**41%**	**41%**	**39%**
Somewhat disagree	20%	21%	23%	22%
Strongly disagree	21%**D**	19%	18%	17%

BASE: U.S. RESPONDENTS

Q25 How strongly do you agree or disagree with each of the following statements?

Summary of Strongly/Somewhat Agree

	2018 (A)	2017 (B)	2016 (C)	2015 (D)
n=	*2,027*	*2,186*	*2,023*	*2,015*
I will use the least expensive grade of gasoline whenever possible.	66%	69%**D**	66%	63%
I assume that any gas sold at the gas station is safe for all of my cars, as well as boats, mowers, chain saws, snow mobiles, generators and other engine products.	65%**CD**	63%**D**	60%	57%
I typically only pay attention to labels on fuel pumps that read "Warning" or "Do Not Use In..."	59%**D**	55%	57%**D**	51%
I always read the labels on fuel pumps.	58%**CD**	55%**D**	53%	50%
When I fuel up my car at the gas station, I check the fuel pump for any warning labels.	53%**D**	53%**D**	50%	47%
I fill up my portable gas tank (i.e., jerry can) with the same fuel used to fill my vehicle.	51%	51%	51%	48%

Summary of Strongly/Somewhat Disagree

	2018 (A)	2017 (B)	2016 (C)	2015 (D)
n=	*2,027*	*2,186*	*2,023*	*2,015*
When I fuel up my car at the gas station, I check the fuel pump for any warning labels.	41%	38%	41%	45%**B**
I always read the labels on fuel pumps.	36%	37%	39%	42%**AB**
I typically only pay attention to labels on fuel pumps that read "Warning" or "Do Not Use In..."	34%	34%	34%	39%**ABC**
I will use the least expensive grade of gasoline whenever possible.	29%**B**	23%	26%	28%**B**
I assume that any gas sold at the gas station is safe for all of my cars, as well as boats, mowers, chain saws, snow mobiles, generators and other engine products.	28%	27%	31%**B**	33%A**B**
I fill up my portable gas tank (i.e., jerry can) with the same fuel used to fill my vehicle.	15%	16%	16%	19%**A**

BASE: U.S. RESPONDENTS
Q30 Which of the following statements do you believe to be true of higher ethanol blends of gasoline?

	2018 (A)	2017 (B)	2016 (C)	2015 (D)
n=	*2,027*	*2,186*	*2,023*	*2,015*
They are safe to use for any gasoline (i.e., non-diesel) engine.	38%**BCD**	31%	31%	30%
HARMFUL/ILLEGAL (NET)	**36%**	**38%D**	**36%**	**33%**
They are harmful to engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products.	33%	33%	31%	30%
They are illegal to use in engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products.	6%**D**	7%**D**	5%**D**	3%
None of these	28%	36%**A**	38%**A**	37%**A**

BASE: U.S. RESPONDENTS
Q35 Which of the following statements do you believe is true?

	2018 (A)	2017 (B)	2016 (C)	2015 (D)
n=	*2,027*	*2,186*	*2,023*	*2,015*
It is **legal** to put high level ethanol gas (i.e., anything higher than 10 percent ethanol) into engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products.	20%**CD**	18%	15%	16%
It is **illegal** to put high level ethanol gas (i.e., anything higher than 10 percent ethanol) into engines such as those in boats, mowers, chain saws, snow mobiles, generators and other engine products.	12%	10%	10%	10%
I am not at all sure.	68%	73%**A**	75%**A**	74%**A**

BASE: U.S. RESPONDENTS

Q40 What kind of fuel do you use for your outdoor power equipment (e.g., lawn mower, garden tractor, chain saw, snow blower, string or line trimmer)?

BASE: All Respondents	**2018 (A)**	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*2,027*	*2,186*	*2,023*	*2,015*
OWN ANY OUTDOOR POWER EQUIPMENT (NET)	**63%D**	**59%**	**60%**	**58%**
EVER PAY ATTENTION TO FUEL TYPE (SUBNET)	**27%CD**	**26%CD**	**22%**	**20%**
0 ethanol	6%	7%	5%	5%
E10	11%**CD**	9%	9%	9%
E15/E30/E50/E85 (SUBNET)	**7%CD**	**7%CD**	**5%**	**4%**
E15	3%**BCD**	1%	1%	1%
E30	2%	2%**D**	1%	1%
E50	1%	1%**C**	*	1%
E85	2%	2%	2%	2%
Other	2%	3%	3%	2%
I do not pay any attention to the type of fuel I use in my outdoor power equipment.	14%	12%	13%	12%
Not sure	22%	22%	25%	26%**AB**
N/A - I do not own any outdoor power equipment.	37%	41%	40%	42%**A**

BASE: Own Any Outdoor Power Equipment	**2018 (A)**	**2017 (B)**	**2016 (C)**	**2015 (D)**
n=	*1,254*	*1,243*	*1,209*	*1,142*
EVER PAY ATTENTION TO FUEL TYPE (NET)	43%**CD**	44%**CD**	36%	35%
0 ethanol	9%	11%	8%	9%
E10	18%	16%	15%	15%
E15/E30/E50/E85 (SUBNET)	11%**D**	12%**CD**	8%	7%
E15	4%**BCD**	2%	2%	1%
E30	2%	4%**D**	2%	1%
E50	1%	2%**C**	*	1%
E85	4%	4%	4%	3%
Other	4%	5%	4%	4%
I do not pay any attention to the type of fuel I use in my outdoor power equipment.	22%	20%	22%	20%
Not sure	35%	37%	42%**AB**	45%**AB**

BASE: OWN ANY OUTDOOR POWER EQUIPMENT

Q45 Which of the following, if any, have you ever done/experienced regarding your outdoor power equipment? Please select all that apply.

	2018 (A)	**2017 (B)**	**2016 (C)**	**2015**
n=	*1,254*	*1,243*	*1,209*	*1,142*
Mixed fuel stabilizer in with the fuel	35%	33%	32%	n/a
Placed equipment into long-term storage without draining the fuel tank	35%**C**	31%	28%	33%
Used an E15 or higher fuel in an engine not designed for it	5%	5%	4%	3%
Used diesel fuel in a non-diesel engine	5%**C**	5%**C**	3%	3%
Other	1%	2%	2%	3%
None	37%	41%	48%**AB**	61%

BASE: OWN ANY OUTDOOR POWER EQUIPMENT

Q50 How strongly do you agree or disagree with each of the following statements?

Summary of Strongly/Somewhat Agree

	2018 (A)	2017 (B)	2016 (C)
n=	*1,254*	*1,243*	*1,209*
When I store gasoline for my outdoor power equipment, I always use a safe container (e.g., a jerry can designed to hold fuel).	84%	80%	83%
I run the tank dry or drain the fuel out of my outdoor power equipment before storing it.	54%	57%	54%
When it comes to fueling my outdoor power equipment, I only use E10 or less gasoline.	53%	50%	49%
I would never put fuel that is more than 30 days old in my outdoor power equipment.	35%	37%	37%
I label the gasoline storage container I use for my outdoor power equipment with the date I purchased the fuel.	29%	35%**AC**	29%

Summary of Strongly/Somewhat Disagree

	2018 (A)	2017 (B)	2016 (C)
n=	*1,254*	*1,243*	*1,209*
I label the gasoline storage container I use for my outdoor power equipment with the date I purchased the fuel.	57%**B**	49%	59%**B**
I would never put fuel that is more than 30 days old in my outdoor power equipment.	53%	48%	51%
I run the tank dry or drain the fuel out of my outdoor power equipment before storing it.	35%	30%	35%**B**
When it comes to fueling my outdoor power equipment, I only use E10 or less gasoline.	24%	25%	27%
When I store gasoline for my outdoor power equipment, I always use a safe container (e.g., a jerry can designed to hold fuel).	6%	6%	5%

BASE: U.S. RESPONDENTS

Q55 How likely would you be to do each of the following if you saw the following image?

Summary of Very/Somewhat Likely

	2018 (A)	2017 (B)
n=	*Variable bases*	*Variable bases*
Make sure I am fueling correctly (i.e., using the correct fuel for the type of engine I am fueling)	89%	87%
Pay more attention to fuel types when I put gas in my outdoor power equipment	86%**B**	82%
Pay more attention to fuel types when I put gas in a jerry can/gasoline can	81%	80%
Research different types of fuel	64%	67%
Change the type of fuel I use	64%	63%

Summary of Not At All/Not Very Likely

	2018 (A)	2017 (B)
n=	*Variable bases*	*Variable bases*
Change the type of fuel I use	36%	37%
Research different types of fuel	36%	33%
Pay more attention to fuel types when I put gas in a jerry can/gasoline can	19%	20%
Pay more attention to fuel types when I put gas in my outdoor power equipment	14%	18%**A**
Make sure I am fueling correctly (i.e., using the correct fuel for the type of engine I am fueling)	11%	13%

BASE: U.S. RESPONDENTS

Q60 As you may already know, E15 fuel is more widely available than it was 2 years ago, yet it is illegal to use in outdoor power equipment as the Environmental Protection Agency (EPA) has deemed it unsafe for use in most outdoor power equipment. There is a small (2.5 x 2.5 inch) warning label that the EPA put out, which is voluntary for gas stations to post on pumps that sell fuel greater than E10.

Do you think the current voluntary warning label is adequate (i.e., fine as is) or inadequate (i.e., the label should be larger, more clear, mandatory) to inform consumers about E15 fuel being illegal to use in outdoor power equipment?

	2018 (A)
n=	*2,027*
Inadequate	63%
Adequate	37%

BASE: U.S. RESPONDENTS

Q65 How much do you agree or disagree with the following statement?

Ethanol-free gas should be more widely available at gas pumps.

	2018 (A)
n=	*2,027*
STRONGLY/SOMEWHAT AGREE (NET)	**66%**
Strongly agree	34%
Somewhat agree	33%
STRONGLY/SOMEWHAT DISAGREE (NET)	**10%**
Somewhat disagree	6%
Strongly disagree	4%
Not sure	24%

ATTACHMENT 3

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NATIONAL RENEWABLE ENERGY LABORATORY

Blender Pump Fuel Survey: CRC Project E-95-2

A. Williams and T.L. Alleman

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List of Acronyms

ASTM	ASTM International
CRC	Coordinating Research Council
EPA	U.S. Environmental Protection Agency
Exx	xx vol% ethanol blended with pure gasoline
MLEB	mid-level ethanol blend
NREL	National Renewable Energy Laboratory
vol%	volume percent

Executive Summary

In 2012, the U.S. gasoline market was about 134 billion gallons [1], and the fuel ethanol market was 13.3 billion gallons [2]. Almost all fuel ethanol is used in gasoline as a 10 volume percent (vol%) blend. A far less significant amount is used as "E85" Flex Fuel (a fuel compliant with ASTM International Specification D5798 and formerly called E85). Mid-level ethanol blends (MLEBs) are an emerging ethanol option that contain more than 10 vol% ethanol but less than 50 vol% ethanol. MLEBs are typically sold as discrete blends, such as 20 vol% (E20), and 30 vol% (E30). The argument for offering MLEBs is to give consumers with Flex Fuel vehicles additional fuel choices at the pump.

The Coordinating Research Council and the U.S. Department of Energy's National Renewable Energy Laboratory conducted a survey of MLEBs in the market, in order to provide a snapshot of selected characteristics of the increasingly diverse array of fuels available to U.S. motorists. A total of 73 fuel samples were collected in February of 2013 from 20 retail stations located in the midwestern United States. Samples included gasoline (E0 or E10), "E85" Flex Fuel, and every MLEB that was offered from each of the 20 stations.

All samples were analyzed by Southwest Research Institute for vapor pressure and ethanol content. For E10 samples there was very little variation in ethanol content. For the MLEB samples variability was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%, and in one case was off by 10 vol%. One of the 20 "E85" Flex Fuel samples was above the allowable limits for ethanol content. Four of the 20 "E85" Flex Fuel samples had vapor pressures below the minimum requirement.

In addition photographs of each station were taken at the time of sample collection, detailing the dispenser labeling and configuration. The style and labeling of the dispenser, hose and nozzle are all important features to prevent misfueling events. Furthermore, the physical location of the MLEB product relative to the gasoline product can also be important to prevent misfueling. In general there were many differences in the style and labeling of the dispensers surveyed in this study.

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Introduction

In 2012, the U.S. gasoline market was about 134 billion gallons [1], and the fuel ethanol market was 13.3 billion gallons [2]. Almost all fuel ethanol is used in gasoline as a 10 volume percent (vol%) blend. A far smaller amount is used in "E85" Flex Fuel (a fuel compliant with ASTM International [ASTM] Specification D5798 and formerly called E85). Mid-level ethanol blends (MLEBs) are an emerging blend of "E85" Flex Fuel and gasoline. MLEBs contain more than 10 vol% ethanol and less than 50 vol% ethanol and are typically sold as discrete blends, such as 20 vol% (E20), and 30 vol% (E30). The argument for offering MLEBs is to offer consumers with Flex Fuel vehicles additional fuel choices at the pump. The recent U.S. Environmental Protection Agency (EPA) waiver allowing up to E15 in 2001 and newer cars, trucks, and sport utility vehicles should increase the volume of MLEBs in the marketplace.

MLEBs are typically offered at stations with blender pumps. A blender pump draws fuel from two separate storage tanks and mixes the fuels to produce the desired ethanol blend ratio. In traditional gas stations, a blender pump is often used to get midgrade gasoline by mixing the regular and premium grade fuels. In a station that offers MLEBs, the blends are generally made by mixing "E85" Flex Fuel with regular gasoline [3].

With the increasing fuel diversity in the marketplace, the Coordinating Research Council (CRC) and the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) conducted a survey of MLEBs in the market. The project assumed that the MLEBs were blended at the dispenser, by a so-called blender pump, from parent gasoline and D5798-compliant "E85" Flex Fuel.

Methodology

Station Identification

The U.S. Department of Energy's Alternative Fuels Data Center was used to identify 20 stations with blender pumps that offered MLEBs. Each station was contacted prior to sample collection to ensure that MLEBs were being sold. While efforts were made to identify stations over a wide geographical area, these stations were all located in the midwestern United States. The relative locations of the stations are illustrated in Figure 1.

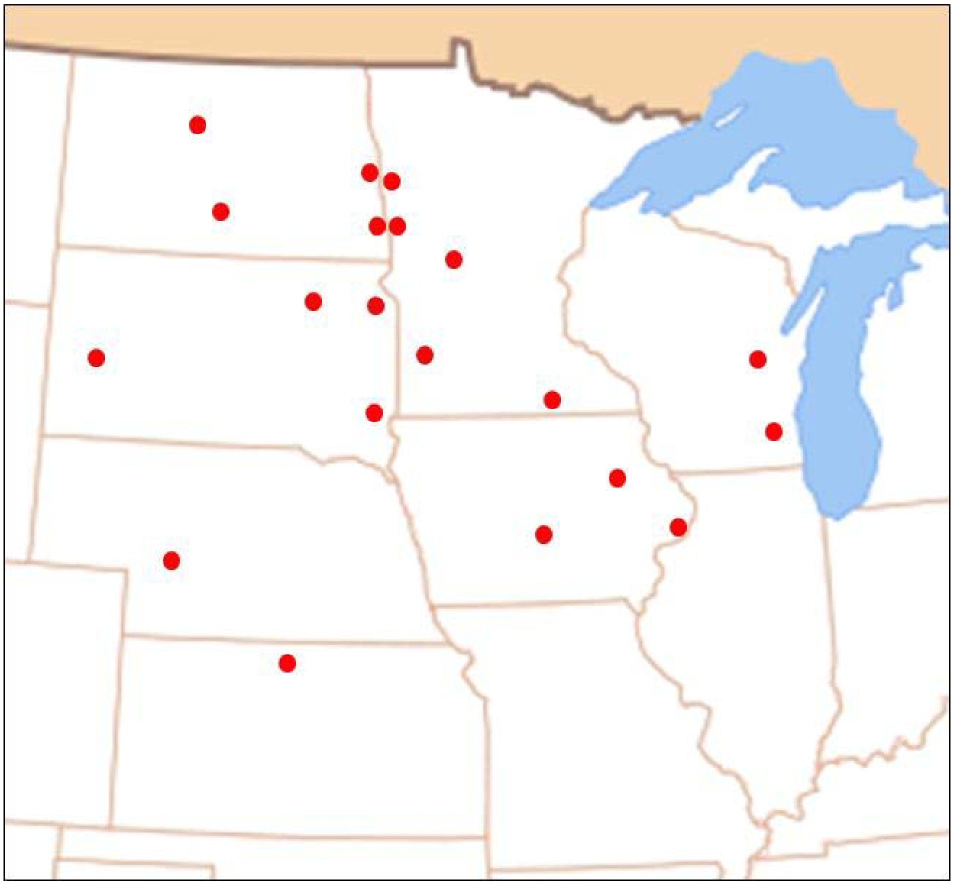

Figure 1. Relative station locations

Sample Collection and Photographs

A contractor was sent to each station to collect the fuel samples. At each station, a 1.5-liter sample was collected from each of the parent fuels (gasoline and "E85" Flex Fuel) along with every MLEB that was offered. In order to prevent sample carry-over, 3 liters of fuel were purged from the pump prior to collection of each individual fuel sample. A total of 73 fuel samples were collected from these 20 retail stations. All fuel samples were collected between February 9th and 26th of 2013, targeting the wintertime class (D5798 Class 4).

In the first E-95 study (2010), samples were collected in ASTM D5798 Class 1, which represents the lowest vapor pressure samples and the warmest months of the year (typically summertime fuels). Between the end of that study and the commencement of the current study, several things changed in the D5798 specification. First, D5798 was updated to reflect the necessity by blenders to adjust the hydrocarbon portion of the blend across a wider range than previously allowed. This change allowed for a consistent, and generally wider range, of allowable ethanol content in each class, with the goal of blenders being able to meet vapor pressure requirements more easily year-round. The second major change was the addition of a fourth class for the wintertime months. The new Class 4 was added in a further effort to help blends produce on-specification fuels in the winter months.

In this most recent study Class 4 fuels were targeted in order to draw the largest contrast to the Class 1 fuels sampled in a previous blender pump survey (CRC E-95) and to expand the limited information on commercially available "E85" Flex Fuel in this new class [4]. In the first E-95 study, multiple tests were run on the Flex Fuel only, such as pHe, acidity, chloride, and sulfate. Results from that work, combined with results from CRC's E-85 studies showed very few failures on these properties, even when the samples failed ethanol content and/or vapor pressure requirements. The decision to not test these properties on the Flex Fuel samples was twofold in this study: first, by reducing the number of tests, a larger number of samples could be collected, and second, with the focus of the study on blender pumps, only the critical properties of the parent fuels were collected (ethanol content and vapor pressure). By reducing the number of tests, the study was able to increase the number of stations from the previous project from 15 to 20, increasing the number of MLEB samples from 25 to 33.

Detailed photographs of the dispensers and stations were also taken at the time of sample collection. These included:

- Close-up photograph of dispenser, showing labeling specific to blends offered
- Photograph showing entire dispenser, including hoses
- Photograph of island including dispenser
- Photograph showing island configuration of MLEB dispenser, in relation to other islands at station
- Photograph of station sign, looking for any indication that MLEBs are being sold at station.

Property Analysis

All fuel samples were analyzed by Southwest Research Institute in San Antonio, Texas. The vapor pressure of the gasoline and the "E85" Flex Fuel was analyzed for comparison to their respective requirements in D4814 and D5798 using ASTM D5191. The vapor pressure of the MLEBs was also measured using the same method. The ethanol content of all fuel samples was analyzed and compared to the appropriate ASTM specification and dispenser labeling captured in the station photographs. Gasoline and E15 blends were analyzed using D5599; ethanol content in samples above E20 was measured by D5501. Samples were also analyzed for water content and specific gravity to allow for ethanol content to be reported in vol%.

Fuel Property Results

Gasoline Samples

To simplify sample collection, the contractor was instructed to sample regular unleaded gasoline, the "E85" Flex Fuel, and all MLEBs offered at each station visited. As discussed below, many of the stations offered E0 and E10. Because no additional direction was given to the contractor about what constituted "regular unleaded gasoline", the samples collected varied and could be either E10 or E0 based on the contractor's individual choice during sampling. In addition, it is unknown whether the MLEBs were blended from E0 or from E10.

Of the 20 stations that were sampled, every location offered Flex Fuel labeled as "E-85." E30 was the most commonly available MLEB, offered at all but two stations. E20 was offered at half of the stations, while E15, E40, and E50 were less common. Thirteen of the 20 stations provided multiple options for MLEBs. One of the stations did not offer any MLEBs, although the station claimed to have the blends during the identification phase of the project. Table 1 shows the number of samples that were collected for each fuel type, along with statistics for the vapor pressure and ethanol content. As illustrated in this table, the ethanol content was generally lower than its indicated value.

Many of the stations offered both hydrocarbon gasoline (E0) as well as oxygenated gasoline (E10). The contractors tasked with collecting the fuel samples only collected one of the two gasoline options. Consequently, 11 samples of hydrocarbon gasoline and 9 samples of oxygenated gasoline were collected from the 20 stations. From the information collected, it was unclear which form of gasoline was used as the parent fuel to make the MLEBs in the blender pump.

Table 1. Summary of Results

Property	**Fuel Type**	**# of Samples**	**Mean**	**Median**	**Standard Deviation**
DVPE, psi	Gasoline (E0)	11	13.4	13.7	1.44
	Oxygenated Gasoline	9	14.4	14.6	0.70
	E15	3	14.2	14.0	0.41
	E20	10	13.9	13.9	0.69
	E30	18	13.5	13.6	0.92
	E40	1	14.2	14.2	NA
	E50	1	13.1	13.1	NA
	"E85" Flex Fuel	20	10.0	10.5	1.64
Ethanol Content, vol%	Gasoline (E0)	11	< 0.1	< 0.1	< 0.1
	Oxygenated Gasoline	9	10.4	10.3	0.10
	E15	3	16.8	17.3	0.92
	E20	10	18.0	17.3	3.35
	E30	18	26.7	26.9	2.59
	E40	1	29.7	29.7	NA
	E50	1	44.2	44.2	NA
	"E85" Flex Fuel	20	70.9	68.3	7.02

DVPE = dry vapor pressure equivalent
NA = not applicable
psi = pounds per square inch

For each of the fuel samples, the ethanol content was determined by the appropriate test method (D5599 or D5501) based on fuel dispenser labeling. Figure 2 shows the results for ethanol content of all samples. The data are organized by station, showing the ethanol content for each product offered at the 20 locations.

For the E10 samples there was very little variation in ethanol content. However, for the MLEB samples variability was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%. The fuels tended to be lower in ethanol content than their indicated amount. Those samples that were furthest from their indicated levels were: E40 from Station #13 (30 vol%), E30 from Station #8 (22 vol%), and both E20 and E30 from Station #7 (12 vol% and 22 vol%, respectively). Also of note is that for stations that offered multiple MLEB products, those MLEBs generally trended either high or low in ethanol content together. The most notable exception was Station #3 where E20 was high at 22 vol% and E30 was low at 26 vol%. In this instance, these two fuels were supplied by separate blender pumps at the same fueling island.

Figure 2 also shows the lower and upper ethanol limit for "E85" Flex Fuel (51 vol% to 83 vol%), per ASTM Specification D5798-13a. As can be seen in the figure, all of the samples were within these limits with the exception of Station #6, which contained 94 vol% ethanol. In 2011, the D5798 specification was changed to reduce the minimum ethanol content from 68 vol% down to 51 vol% to allow for more high volatility hydrocarbon in the blends, which should result in an increase in vapor pressure. The E-85-1 and E-85-2 CRC reports both found that samples had difficulty meeting wintertime vapor pressure [5, 6]. The difficulty in meeting winter vapor pressure of "E85" Flex Fuel was one widely cited reason for a cessation of sales of "E85" Flex Fuel by Marathon Petroleum Company in 2009 [7]. In response to general industry difficulties, ASTM reduced the minimum ethanol content for all classes and added the fourth class to help ensure these fuels were fit for purpose.

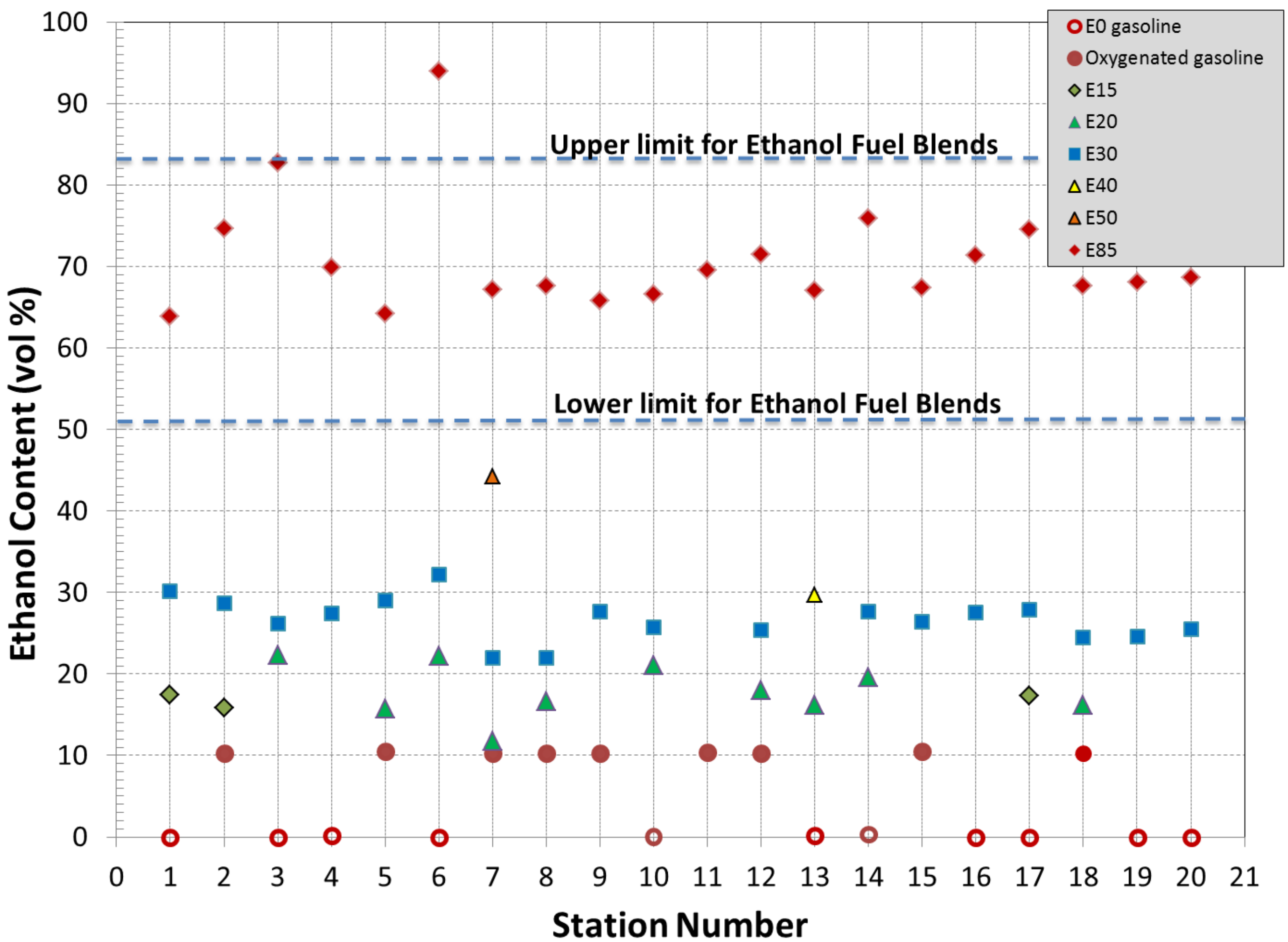

Figure 2. Ethanol content for all fuel samples

Gasoline and "E85" Flex Fuel are required to meet specifications for fuel vapor pressure that are dependent on location and time of year. All but one of the "E85" Flex Fuel samples in this survey would fall under D5798-11 Class 4, with a vapor pressure requirement of 9.5 to 15.0 psi. The one exception would be sample #14, collected in Kansas, which is listed as Class 3/4 for the month of February. The Class 3 vapor pressure requirement is 8.5 to 12.0 psi. Figure 3 shows the vapor pressure for all of these fuel samples along with the vapor pressure requirements for "E85" Flex Fuel. Four of the 20 "E85" Flex Fuel samples collected have vapor pressure below their minimum requirement, for a failure rate of 20%. For comparison, of the 37 Class 3 "E85" Flex Fuel samples collected in a previous fuel survey, the failure rate was 70% [6]. The extremely low vapor pressure of "E85" Flex Fuel collected at Station #6 is explained by the high level of ethanol (94 vol%).

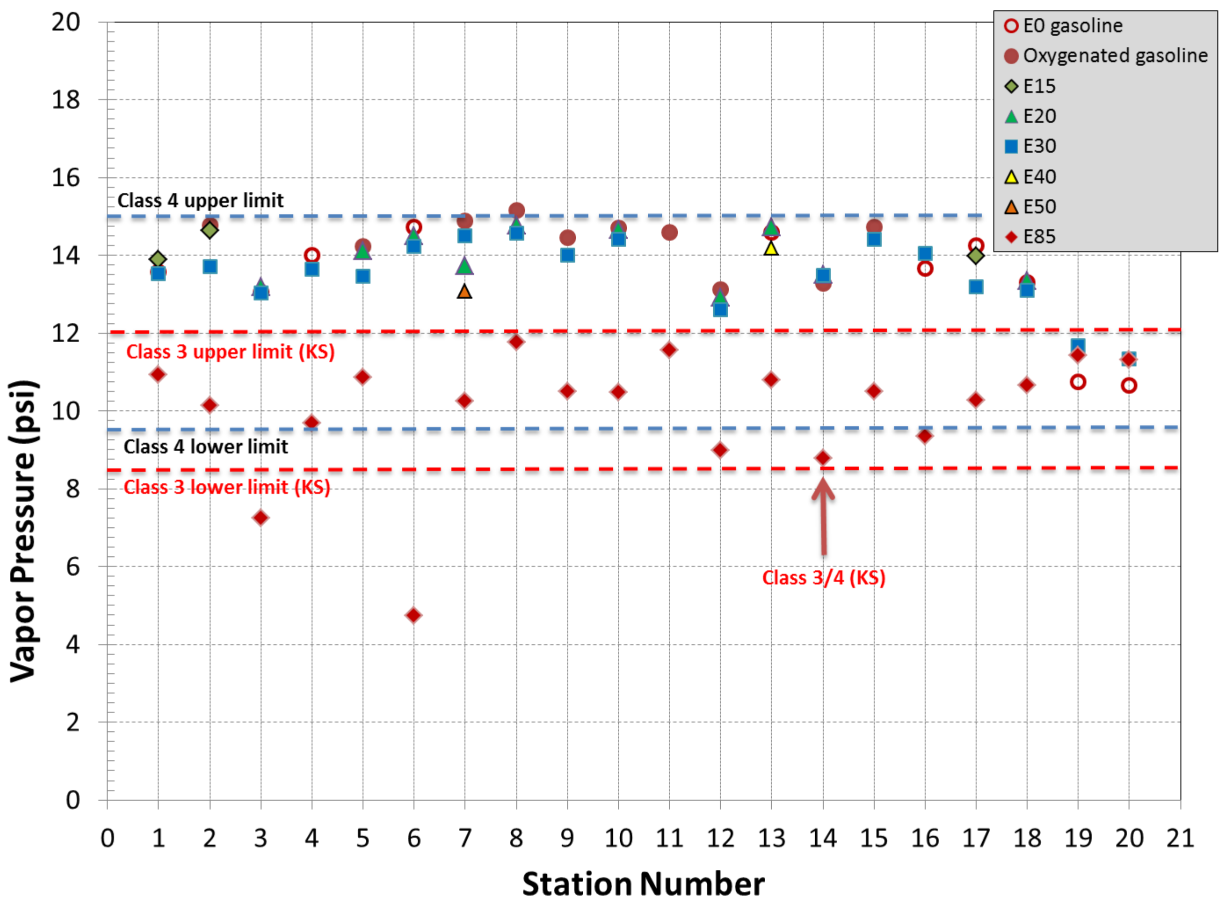

Figure 3. Vapor pressure for all fuel samples

Station Photos

An additional objective of this survey was to understand MLEB dispenser labeling. To make this assessment, detailed photographs of the stations and dispensers were taken at the time of sample collection. The style and labeling of the dispenser, hose, and nozzle are all important features to minimize the probability of misfueling events. Furthermore, the physical location of the MLEB product relative to the gasoline product can also be important to prevent misfueling. As part of the E15 partial waiver, the EPA requires obligated parties to submit a Misfueling Mitigation Plan [8]. In March of 2012, the EPA concluded that a model plan developed by the Renewable Fuels Association was sufficient to satisfy this partial waiver requirement. As part of this model plan, the Renewable Fuels Association describes three configurations where blender pumps are used to produce E15. They are as follows:

1. A dedicated E15 dispenser or a dedicated E15 hose at a multiple fuel dispenser.
2. E15 from the same nozzle and hose as E10. This creates the potential for a vehicle not included under the E15 partial waiver to receive residual amounts of E15 when fueling with E10.
3. E15 from the same nozzle and hose as higher ethanol blends. This creates the potential for non-Flex Fuel vehicles to receive residual amounts of higher ethanol blends when being fueled with E15.

While the Renewable Fuels Association's Misfueling Mitigation Plan was written specifically for E15, we make an assessment here of how the stations in this survey offer MLEBs in comparison to the model plan guidelines. Three of the 20 stations in this survey offered E15 from the same nozzle and hose as higher ethanol blends (Configuration #3). Photos of this dispenser configuration as represented by these three stations are shown in Figures 4, 5, and 6. In addition, two of the 20 stations offered higher ethanol blends from the same hose as E10 (similar to Configuration #2). Photos of the dispensers in these two stations are shown in Figures 7 and 8. Each of the dispenser configurations in these five stations create the potential for introduction of residual amounts of higher ethanol fuel than is acceptable in non-Flex Fuel vehicles. Photographs of the other stations are included in the appendix.

Figure 4. Station #1 offered E15 from same nozzle as higher ethanol blends

Figure 5. Station #2 offered E15 from same nozzle as higher ethanol blends

Figure 6. Station #17 offered E15 from same nozzle as higher ethanol blends

Figure 7. Station #3 offered higher ethanol blends from the same hose as E10

Figure 8. Station #14 offered higher ethanol blends from the same hose as E10

Photographs of each station can be found in the appendix. Other general observations that can be noted from these photographs are listed below.

- Most of the pumps that offered "E85" Flex Fuel were labeled as "minimum 70% ethanol," which was not the case in 11 of the 20 survey samples analyzed (see Figure 2) and likely represents old labeling from 2010 or earlier, when D5798 set minimum ethanol content at 70%.
- While yellow color coding is common for MLEB dispenser nozzles and hoses, it is not universal. Four of the 20 stations did not have yellow dispenser nozzles and hoses for MLEB fuels.
- Six of the stations which offered a single MLEB alongside "E85" Flex Fuel, offered the two products from separate hoses.

- Three of the stations listed an octane number for the MLEBs that they offered.

Table 2 lists the MLEB offerings and blender pump configurations for each station sampled.

Table 2. Description of Blender Pump Station Configuration

Station #	MLEB offerings	Notes on Dispenser Configuration
1	E15, E30	E15 offered from the same hose as E30 and "E85" Flex Fuel
2	E15, E30	E15 offered from the same hose as E30 and "E85" Flex Fuel
3	E20, E30	E10 offered from the same hose as E20 and "E85" Flex Fuel
4	E30	Dedicated MLEB hose
5	E20, E30	Dedicated MLEB hose
6	E20, E30	Dedicated MLEB hose
7	E20, E30, E50	Dedicated MLEB hose
8	E20, E30	Dedicated MLEB hose
9	E30	Dedicated MLEB hose
10	E20, E30	Dedicated MLEB hose
11	NA	No MLEB was offered at this station
12	E20, E30	Dedicated MLEB hose
13	E20, E40	Dedicated MLEB hose
14	E20, E30	E10 offered from the same hose as E20, E30 and "E85" Flex Fuel
15	E30	Dedicated MLEB hose
16	E30	Dedicated MLEB hose
17	E15, E30	E15 offered from the same hose as E30 and "E85" Flex Fuel
18	E20, E30	Dedicated MLEB hose
19	E30	Dedicated MLEB hose
20	E30	Dedicated MLEB hose

Conclusions

In this work, 73 samples were collected from 20 separate blender pump stations located in the midwestern United States. Class 4 was targeted, with samples collected in February of 2013. This study was a follow-up to an earlier MLEB fuel survey (CRC E-95), which focused on Class 1 fuels. Samples were analyzed by Southwest Research Institute for ethanol content and vapor pressure. In addition detailed photographs of the stations were collected at the time of sampling. Key findings in this survey are listed below:

- For the E10 samples there was very little variation in ethanol content.
- For the MLEB samples variability in ethanol content was higher, typically failing to meet the advertised ethanol level by 3 to 4 vol%, and in one case was off by 10 vol%.
- One of the 20 "E85" Flex Fuel samples was above the allowable limits for ethanol content.
- Four of the 20 "E85" Flex Fuel samples had vapor pressure below the minimum requirement for Class 4.
- In general, there were many differences in the style and labeling of the dispensers surveyed in this study. Five of the 20 dispensers offered higher MLEBs (>E15) from the same hose as E10 or E15. These five dispensers create the potential for introduction of residual amounts of higher ethanol fuel than is acceptable in non-Flex Fuel vehicles.

Both the E-95 and E-95-2 study focused on MLEBs offered in the midwestern United States. Although the surveys were somewhat limited by where the stations were located, the goal was to find states with the highest number of stations, then sample a subset in each state. Thus, states with only one or two blender pumps were excluded from sampling.

The station locations in the previous study were rural, in areas that were not required to meet any of the footnotes in Table 4 in D4814, the gasoline specification. The footnotes in D4814 cover vapor pressure requirements during summer months for Federal ozone non-attainment areas, areas requiring reformulated gasoline, and/or areas that have state implementation plans for control of air quality. Future work may consider another summertime survey, particularly in areas where specific requirements are in place for gasoline, to determine if these gasolines have any impact on “E85” Flex Fuel properties compared to gasolines found in rural areas. Future work may also consider a wider distribution of sampling locations, including states where only one or two blender pumps may be located.

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Acknowledgments

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Appendix A: Station Photographs

Figure A.1 Station #4

Figure A.2 Station #5

Figure A.3 Station #6

Figure A.4 Station #7

Figure A.5 Station #8

Figure A.6 Station #9

Figure A.7 Station #10

Figure A.8 Station #11

Figure A.9 Station #12

Figure A.10 Station #13

Figure A.11 Station #15

Figure A.12 Station #16

Figure A.13 Station #18

Figure A.14 Station #19

Figure A.15 Station #20

Appendix B: Tabulated Fuel Property Data

Table B.1 Fuel Properties

Station Number	Indicated Nominal	Ethanol Content (D5501/D5599) vol%	DVPE (D5191) psi	Water (D6304) vol%	SPGr@60F (D4052)
1	E85	63.9	10.9	0.63	0.77
1	E15	17.4	13.9		0.73
1	E30	30.2	13.5	0.35	0.74
1	E0	<0.1	13.6		0.72
2	E15	15.8	14.6		0.73
2	E30	28.6	13.7	0.33	0.74
2	E85	74.7	10.1	0.76	0.76
2	E10	10.3	14.8		0.73
3	E20	22.4	13.2	0.23	0.73
3	E85	82.7	7.2	0.80	0.78
3	E0	<0.1	13.1		0.72
3	E30	26.2	13.0	0.28	0.74
4	E85	69.9	9.7	0.72	0.77
4	E0	0.2	14.0		0.72
4	E30	27.4	13.7	0.29	0.74
5	E10	10.5	14.2		0.73
5	E85	64.2	10.9	0.57	0.76
5	E30	29.0	13.5	0.23	0.74
5	E20	15.7	14.1	0.17	0.73
6	E20	22.2	14.5	0.23	0.73
6	E0	<0.1	14.7		0.72
6	E85	93.9	4.7	0.81	0.79
6	E30	32.2	14.2	0.31	0.74
7	E30	22.0	14.5	0.33	0.74
7	E20	11.8	13.7	0.12	0.73
7	E10	10.3	14.9		0.73
7	E85	67.1	10.3	0.52	0.77
7	E50	44.2	13.1	0.44	0.75
8	E20	16.7	14.8	0.17	0.73
8	E10	10.3	15.2		0.73
8	E30	22.0	14.6	0.23	0.73
8	E85	67.6	11.8	0.72	0.75
9	E10	10.3	14.5		0.73
9	E85	65.8	10.5	0.62	0.77
9	E30	27.6	14.0	0.27	0.74

Station Number	Indicated Nominal	Ethanol Content (D5501/D5599) vol%	DVPE (D5191) psi	Water (D6304) vol%	SPGr@60F (D4052)
10	E0	<0.1	14.7		0.72
10	E85	66.6	10.5	0.63	0.77
10	E20	21.1	14.7	0.21	0.74
10	E30	25.7	14.4	0.25	0.74
11	E10	10.4	14.6		0.73
11	E85	69.6	11.6	0.56	0.75
12	E10	10.3	13.1		0.73
12	E20	17.9	12.9	0.18	0.73
12	E85	71.4	9.0	0.53	0.77
12	E30	25.4	12.6	0.23	0.74
13	E40	29.7	14.2	0.34	0.74
13	E0	0.1	14.6		0.72
13	E20	16.2	14.7	0.17	0.73
13	E85	67.0	10.8	0.66	0.77
14	E30	27.7	13.5	0.22	0.74
14	E20	19.6	13.5	0.15	0.73
14	E85	75.8	8.8	0.61	0.78
14	E0	0.3	13.3		0.72
15	E10	10.5	14.7		0.73
15	E30	26.4	14.4	0.27	0.74
15	E85	67.4	10.5	0.75	0.77
16	E85	71.3	9.4	0.76	0.78
16	E0	<0.1	13.7		0.73
16	E30	27.6	14.1	0.28	0.74
17	E30	27.8	13.2	0.26	0.73
17	E0	<0.1	14.3		0.72
17	E15	17.3	14.0		0.73
17	E85	74.5	10.3	0.58	0.76
18	E30	24.5	13.1	0.28	0.74
18	E10	10.2	13.3		0.73
18	E20	16.2	13.4	0.18	0.74
18	E85	67.6	10.7	0.40	0.77
19	E0	<0.1	10.7		0.73
19	E85	68.0	11.4	0.47	0.75
19	E30	24.6	11.7	0.26	0.74
20	E85	68.6	11.3	0.57	0.75
20	E30	25.5	11.3	0.19	0.74
20	E0	<0.1	10.7		0.73

ATTACHMENT 4

OVERVIEW –IMPACTS OF MID-LEVEL ETHANOL ON-ROAD AND NON-ROAD ENGINES AND EQUIPMENT (PREPARED BY DR. RON SAHU, MAY 15, 2009)

A. Change Due to the Enleanment Effect of Ethanol

Gasoline is a mixture of many hydrocarbon compounds that consist mainly of hydrogen and carbon.[1] Ethanol also contains hydrogen and carbon – but, in addition, it also contains oxygen. The exact air-to-fuel ratio needed for complete combustion of the fuel (to carbon dioxide and water vapor) is called the "stoichiometric air-to-fuel ratio." This ratio is about 14.7 to 1.0 (on weight basis) for gasoline. For ethanol/gasoline blends less air is required for complete combustion because oxygen is contained in the ethanol and because some of the hydrocarbons have been displaced. For example, for E10 the stoichiometric air-to-fuel ratio is 14.0 to 14.1 pounds of air per pound of fuel. Indeed, the stoichiometric air-to-fuel ratio for straight ethanol is 9 to 1 so that as the proportion of ethanol in the gasoline blend increases so must the air-to-fuel ratio decrease. To deliver the required power for any given operating condition, engines consume enough air and fuel to generate the energy required, to the limit of the engine's capabilities. Because fuel delivery systems are designed to deliver the prescribed amount of fuel on a volume control basis the fuel volume delivered is related to the volume of air introduced. The engine design anticipates that the fuel utilized will match the air-to-fuel ratio characteristics utilized in the engine design and calibration. Because ethanol blended fuels require more fuel for the same amount of air to achieve stoichiometric conditions, the fuel system must adapt by introducing more fuel or the desired mixture is not achieved. If additional fuel is not introduced to compensate for the ethanol the resulting mixture has less fuel than desired; the effect of this type of fuel change on an engine is called "enleanment."

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1 Sulfur, nitrogen, and trace elements also may be present.

Even with closed-loop systems, where the engine has a control system that can detect and compensate for the effects of ethanol addition (adapt), if the fuel contains an amount of ethanol that is outside the range of the system design, the engine similarly may receive too much oxygen and operate in a lean condition. Lean operation can lead to a variety of performance problems, for example the combustion and exhaust gas temperatures will be higher, engine starting may become more difficult, and the engine speed control may become inaccurate.[2] These problems may result in the unintentional engagement of cutting chains and blades on chainsaws and other products – because the engines driving these products will run at higher speeds, especially at idle conditions.

The increased combustion and exhaust gas temperatures resulting from lean operation can result in severe damages to pistons, gaskets, catalysts and emissions-related components, in turn, resulting in the failure of the product to operate and increased exhaust emissions.[3] These increased temperatures can also damage and destroy critical safety components like spark arrestors – as required by the U.S. Forest Service to be used on chainsaws to reduce fire risks.

B. Effect on Exhaust Emissions

Enleanment and the increased heat from mid-level ethanol blends will cause heat-related damage to the engine over its useful life, which can cause dramatic increases in hydrocarbon emissions. NOx emissions from conventional products and vehicles generally increase

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2 Issues associated with driveability and operational problems have been discussed for on-road vehicles and for off-road equipment in a series of reports in 2002-2004 by Orbital Engine Company for a biofuels assessment conducted in Australia. In particular, see (a) A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines, January 2003; (b) Marine Outboard Driveability Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on a Small Batch of Engines, February 2003 and (c) A Testing Based Assessment to Determine Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Passenger Vehicle Fleet – 2000hrs Material Compatibility Testing, May 2003.

3 Id.

immediately since enleanment creates conditions which increase NOx.[4] For less sophisticated open-loop engines, NOx emission increases can be dramatic.

While some of the toxics in exhaust emissions show expected decreases in the presence of ethanol, some toxics, such as aldehydes, can show increases. Besides the potential toxic effects of aldehydes in exhaust gases, the aldehydes act as an ozone precursor and increase the smog-forming potential.

C. Effect on Water Solubility and Phase Separation

Separation of a single phase gasoline into a "gasoline phase" and a "water phase" can occur when too much water is introduced into the fuel tank. Water contamination is most commonly caused by improper fuel storage practices at the fuel distribution or retail level, or the accidental introduction of water during vehicle refueling. Water has a higher density than gasoline, so if water separates, it will form a layer below the gasoline. Because most engines obtain their fuel from, or near, the bottom of the fuel tank, engines will not run if the fuel pick up is in the water-phase layer.

Typically, gasoline can absorb only very small amounts of water before phase separation occurs. Ethanol/gasoline blends, due to ethanol's greater affinity with water, can absorb significantly more water without phase separation occurring than gasoline. Ethanol blends can actually dry out tanks by absorbing the water and allowing it to be drawn harmlessly into the engine with the gasoline. If, however, too much water is introduced into an ethanol blend, the water and most of the ethanol will separate from the gasoline and the remaining ethanol. The amount of water that can be absorbed by ethanol/gasoline blends, without phase separation, varies from 0.3 to 0.5 volume percent, depending on temperature, aromatics, and ethanol content.

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4 The higher combustion temperatures and the excess of oxygen in the combustion chamber result in the excess oxygen combining with nitrogen to produce nitrogen oxides.

If phase separation were to occur, the ethanol/water mixture would be drawn into the engine and the engine would most likely stop.

In some situations, ethanol/gasoline blends might absorb water vapor from the atmosphere, leading to phase separation. Such problems are of greater concern for engines with open-vented fuel tanks that are operated in humid environments, such as marine engines.

Additionally, more complex phenomena such as lubricating oil/fuel separation (in 2-stroke engines) and temperature-induced phase separation of various fuel components have also been noted.

D. Effect on Material Compatibility

A variety of components in engine/equipment systems can come into contact with the fuel. These include

- Fuel Lines
- Fuel Tanks
- Fuel Pumps
- Fuel Injectors
- Fuel Rails
- Carburetors (and internal components)
- Pressure Regulators
- Valves
- O-Rings
- Gaskets

Materials used in these components should be compatible with the full range of expected fuel composition. Table A shows the types of metals, rubbers, and plastics that are used in existing engines and fuel system components currently designed to run on E10 fuel blends.

Table A – Illustrative Materials Used in Engines and Fuel Systems

Table A

A. Metals

- Aluminum (various grades)
- Brass
- Carbon Steel
- Cast Iron
- Copper
- Magnesium (and alloys)
- Zinc (and alloys)
- Lead
- Tin
- Terne Plate
- Solder (tin/lead)
- Other metals and alloys

B. Rubbers

- Buna N
- Silicon Rubber (VMQ)
- HNBR (Hydrogenated Nitrile Butadiene Rubber)
- Others

C. Plastics/Polymers/Monomers/Elastomers

- Hydrin (epichlorohydrin)
- H-NBR (copolymer from butadiene and acrylonitrile)
- Low Temp Viton (FKM) grades such as GFLT
- Nylons (various grades)
- Polyester urethane foam
- NBR with 16% PVC and 32% ACN content
- Ozo-Paracril (blend of PVC and nitrile rubbers)
- CSM - Chlorosulfonated polyethylene, such as Hypalon
- FVMQ - Fluorosilicone
- HDPE – High Density Polyethylene
- PS - Polysulfone
- PC - Polycarbonate
- ABS - Acrylonitrile Butadiene Styrene
- EVOH -Ethylene Vinyl Alcohol
- PPA - Polyphtalamide
- PBT - Polybutylene Terephthalate
- PE - Polyethylene – High Density Polyethylene (HDPE),
- PE - LDPE Low Density Polyethylene (LDPE)
- PET - Polyethylene Terephthalate (Mylar)
- PP - Polypropylene
- PPS - Polyphenylene Sulfide
- PUR - Polyurethane
- PVC - Polyvinyl Chloride
- PEI - Polyetherimide (GE Ultem)
- POM - Acetel Copolymer
- HTN - DuPont™ Zytel® HTN
- PTFE - Polyteraflouroethylene (Teflon)
- POM - Polyoxymethylene (acetal/Delrin)
- Fluorosilicones

Others

This is not an exhaustive list and is meant as an illustration of the diversity of materials used presently. Based on existing studies, it is clear that several rubbers and elastomers can swell and deteriorate more rapidly in the presence of ethanol.[5] Ethanol also corrodes certain metals. Corrosion occurs through different mechanisms including acidic attack, galvanic activity, and chemical interaction. The first is caused by water in the fuel. Ethanol attracts and dissolves water, creating a slightly acidic solution. Unlike gasoline, ethanol alone or combined with water conducts electricity; this conductivity creates a galvanic cell that causes exposed metals to corrode. So when ethanol is blended with gasoline the resulting blend is conductive and the conductivity increases as the amount of ethanol is increased. The addition of ethanol greatly increases the ability of gasoline to dissolve ionic impurities which can facilitate corrosive attach of many metals. Another mechanism is direct chemical interaction with ethanol molecules on certain metals.

Clearly, deterioration of materials would result in loss of function of critical engine components, resulting in fuel leaks, fires from fuel leaks, and equipment failure. This has obvious safety implications.

E. Effect on Evaporative Emissions

Permeation of fuel through elastomers can result in deterioration of these materials. In recent testing, all of the tested ethanol blends showed higher permeation rates through elastomers

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5 A Testing Based Assessment to Determine Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Passenger Vehicle Fleet – 2000hrs Material Compatibility Testing, May 2003 and A Testing Based Assessment to Determine Impacts of a 10% and 20% Ethanol Gasoline Fuel Blend on Non-Automotive Engines - 2000hrs Material Compatibility Testing, May 2003.

than conventional gasoline.[6] An important emissions concern that remains poorly understood is ethanol's ability to permeate through rubber, plastic, and other materials used widely in the fuel tank, fuel system hoses, seals, and other parts of the fuel handling system. Recent studies have shown these emissions can be quite significant.[7]

F. Impacts Associated with Fuel Volatility

Mid-level ethanol gasoline blends are documented as causing the following operating problems resulting from their different volatility and vaporization characteristics. First, because ethanol has a lower vapor pressure, it has been shown to cause starting problems because there is inadequate vapor pressure to a vapor mixture rich enough to ignite. In turn, such problems could result in consumer tampering of the engine's carburetor.

Second, because ethanol vaporizes at lower temperatures than gasoline, mid-level ethanol can cause "vapor lock." Vapor lock is a condition where the fuel in the engine's fuel delivery system vaporizes preventing the transport of liquid fuel to the carburetor or fuel injectors. Increasing the ethanol concentration beyond E10 is likely to increase the likelihood of vapor lock for open loop fuel control system engines typically used on older vehicles and most off-road engines. Even in the closed loop engine systems used in some off-road engines and in most late-model vehicles, there remains the likelihood of vapor lock.

Other concerns about low temperature fuel characteristics of ethanol blends include a) increased viscosity of ethanol/gasoline blends which may impede fuel flow and b) phase separation in the vehicle fuel system due to reduced water solubility.

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6 (a) See EPA-420-D-06-004, Draft Regulatory Impact Analysis: Control of Hazardous Air Pollutants from Mobile Sources, Chapter 7, February 2006. (b) See also, Fuel Permeation from Automotive Systems: E0, E6, E10, E20, and E85, Final Report, CRC Project No. E-65-3, December 2006.

7 See, e.g.:, the CRC E-65-3 Project Report referenced earlier as well as the EPA document referenced earlier which also discusses testing conducted by the California Air Resources Board.

G. Summary of Impacts

The effects of increased ethanol in gasoline are generally not linear with the amount of oxygen in the fuel. Hence, the effects of increasing the ethanol content beyond E10 on current engines are not fully known. Table B presents an overview of all these effects and how they can influence emissions, performance, and durability, mainly for automobiles; but, in some instances, the effect of increased ethanol on less sophisticated off-road engines is also noted.

Table B
Properties of Ethanol And Associated Implications

Property	*Implication*
Hydrogen Bonding/Vapor Pressure	This makes pure ethanol have a very low vapor pressure compared to gasoline. But it also means the vapor pressure of a mixture can be higher than the gasoline alone. Where the peak vapor pressure occurs depends on the base gasoline vapor pressure and ethanol concentration. With a 9 RVP base gasoline, the peak occurs at around 6-7% by volume.[8] Vapor pressure directly affects the evaporation rate and potential hydrocarbon emissions.
Hydrogen Bonding/Water Attraction	Easy hydrogen bonding makes ethanol attract water. The presence of water, in turn, increases the risk that certain metals will corrode. This becomes a problem when fuel remains in storage (including vehicle fuel tanks) and handling systems for a long time.
Oxygen Atom	Ethanol's oxygen atom lowers its energy content, which reduces fuel economy. A blend's final energy content and the impact on fuel economy depends on the amount of ethanol and gasoline density. Most blends up to 10% ethanol by volume do not affect fuel economy to a significant extent (about 1-3%).
Oxygen Atom	Ethanol mixed with gasoline makes the air-to-fuel ratio leaner than with gasoline alone. Controlling the air-to-fuel ratio is critical to the combustion process and engine performance. Performance problems include hesitation, stumbling, vapor lock, and other impacts on drivability. Pre-ignition also can occur, causing engine knock and potential damage. Ambient temperature and pressure are important factors.
Oxygen Atom	Manufacturers calibrate the oxygen sensors (used in modern vehicle technologies but not in off-road equipment, in general) to recognize specific levels of oxygen in the exhaust stream. If a mixture is outside the calibration range, the sensor will send inaccurate signals to the air-to-fuel feedback and on-board diagnostic systems. This could cause improper air-to-fuel ratios as well as an increased risk of causing one of the dashboard's warning lights (MIL) to illuminate.
Higher Combustion Temperature	This increases the formation of NOx, an ozone precursor, in the exhaust gas. Modern three-way catalysts in vehicles reduce NOx by more than 99%, except before the catalyst fully warms up (i.e., during cold-start engine operation). Excessive combustion temperatures also can cause engine damage.
Higher Latent Heat of Vaporization	This can delay catalyst "light-off," which is period of time before the catalyst warms up and can reduce exhaust emissions of HC, CO, and NOx.
Higher Electrical Conductivity	This property increases galvanic corrosion of metals.
Permeability	Ethanol readily permeates at significant rates through elastomers, plastics, and other materials used widely for hoses, o-rings, and other fuel system parts. Depending on temperature and the materials used in the fuel system, this can significantly increase

[8] See API Publication 4261, June 2001

	hydrocarbon emissions.
Solvency	Under certain conditions, the presence of ethanol can cause certain detergency additives to precipitate out of solution, leaving the engine unprotected from gummy deposits. Deposits can increase emissions, lower fuel economy, and increase drivability problems.
Polarity or Oxygen Atom	Ethanol lowers fuel lubricity by binding to metal surfaces and displacing motor oil. This effect increases cylinder bore wear.
Solvency	Ethanol is an effective solvent that mixes readily with both polar and non-polar chemicals. This property allows ethanol to dissolve some adhesives used to make paint adhere to vehicle bodies. Ethanol also dissolves certain resins and causes them to leach out of the fiberglass fuel tanks used in some boats. Not only does this cause the tank to deteriorate, it also creates a sludge that coats the engine and can cause stalling and other performance problems.[9]

9 See "Important News for Boat Owners," at www.ethanolrfa.org.

H. Ethanol-Compatible Design

It is instructive to review the types of changes that have been made in certain automobiles to handle greater than E10 fuels. Table C, below, shows the types of changes that have been made in Brazilian vehicles in order to accommodate higher ethanol blends.

Table C
Adaptation of Brazilian Vehicles[10] for Use with E22 or E85+[11]

System	Part Change
Air-Fuel Feed	Electronic fuel injectors: must use stainless steel and modify the design to improve fuel "spray" and throughput. Manufacturers calibrate the system to the fuel, to ensure the proper air-to-fuel ratio and an appropriate Lambda sensor working range.
	Carburetors: must treat or otherwise protect aluminum or zinc alloy surfaces.
Fuel Handling System	Fuel pumps: must protect internal surfaces and seal connectors; a different metal may be required.
	Fuel pressure regulators: must protect internal surfaces; internal diaphragm may need to be up-graded.
	Fuel filter: must protect internal surfaces and use an appropriate adhesive for the filter element.
	Fuel tank: if metallic, must protect (coat) the internal surface. If plastic, may need to line the interior to reduce permeation.
	Fuel lines and rails: may need to coat steel parts with nickel to prevent corrosion or replace with stainless steel.
	Fuel line quick connects: must replace plain steel with stainless steel.
	Hoses and seals: "o-ring" seals and hoses require resistant materials.
Emission Controls	Vapor control canister: may need to increase the size of the canister and recalibrate it for the expected purge air flow rate.
	Catalyst: may need to adjust the kind and amount of catalyst and wash coating.
Powertrain	Ignition System: must recalibrate ignition advance control.
	Engine: should use a higher compression ratio for proper operation; new camshaft profile and phase; and new materials for the intake and exhaust valves and valve seats.
	Intake manifold: must be able to deliver air at a higher temperature; requires a new profile and must have a smoother surface to increase air flow.
	Exhaust pipe: must protect (coat) the internal surfaces and ensure design can handle a higher amount of vapor.
Other	Fuel filler door paint: must change paint formula used on plastic fuel filler door to avoid loss of paint adhesion.
	Motor oil: may require reformulation and/or a new additive package.
	All parts that might be exposed to the fuel: avoid polyamide 6.6 (nylon), aluminum, and various zinc alloys. If these materials are used, their surfaces must be treated or otherwise

10 Brazil's vehicle emission standards are less stringent than those in the U.S., so U.S. vehicles may require additional effort and calibration to meet emission and durability standards.

11 "Fuel Specifications in Latin America: Is Harmonization a Reality?" Henry Joseph Jr., ANFAVEA (Brazilian Vehicle Manufacturers Association), presented at the Hart World Fuels Conference, Rio de Janeiro, 21-23 June 2004.

	protected.
	Vehicle suspension: may need to modify to accommodate a higher vehicle weight
	Cold start system (for E85or above): may require an auxiliary start system with its own temperature sensor, gasoline reservoir, extra fuel injector, and fuel pump; also, the vehicle battery must have a higher capacity.

For automobiles designed to handle greater than E10, the changes involve the use of innovative and ethanol-compatible technologies, material changes, and adjustments in calibration. In all cases, one cannot adapt or retrofit existing products because too many parts and design steps are involved and the product may have size constraints. Necessary modifications must occur during design and production to ensure compliance with strict emission standards and to meet consumer expectations for safety, durability, performance, and cost.

To ensure materials compatibility at higher ethanol levels for use with flexible fuel vehicles (FFVs), manufacturers use corrosion resistant materials in any part that may contact fuel. For example, Brazilian auto manufacturers, who have considerable experience producing ethanol-compatible vehicles, recommend using electronic fuel injectors made with stainless steel, larger holes, and modified designs to improve fuel spray. Significant changes to the fuel pump and fuel pump motor are also often needed. Similarly, manufacturers of carbureted engines—for example, almost all small engine products such as chain saws and lawn mowers, as well as older and antique vehicles—recommend, among other steps, coating or anodizing aluminum carburetors or substituting a different metal not susceptible to attack.

Boats have similar compatibility concerns. Many, for example, use aluminum fuel tanks that are susceptible to corrosion. While sacrificial zinc anodes often are added later to the external parts of these tanks, they are not feasible for the tank's interior.[12] Older yachts with fiberglass tanks have a different problem. Ethanol can chemically attack some of the resins used

12 NMMA Ethanol Position Paper, no date, available at www.nmma.org/government/environmental/?catid=573.

to make these tanks causing them to dissolve. In doing so, the ethanol causes leaks, heavy black deposits on marine engine intake valves, and deformation of push rods, pistons, and valves.[13]

Conventional vehicles and products do not have these material adaptations for higher level ethanol use. One device particularly difficult to address after-the-fact is the fuel tank level sensor. These sensors, which are placed inside the fuel tank, directly expose wiring to the fuel. Depending on how much ethanol these devices contact and for how long, galvanic or electrolytic corrosion would be expected to dissolve the wires and eventually cause device failure.

Manufacturers make additional design changes to address emissions and performance needs.[14] In this context, it is important to remember that U.S. emission standards are more stringent than those in Brazil. For U.S. vehicles, manufacturers select oxygen sensors and onboard diagnostic (OBD) systems specifically to cover the expected range of oxygen in the exhaust gas. If the fuel ethanol pushes the exhaust oxygen content outside the range of the oxygen sensor, the vehicle's OBD system won't work properly and may erroneously illuminate or fail to illuminate the dashboard warning light. In addition, manufacturers must calibrate vehicle and product systems to the expected fuel to ensure the proper air-fuel ratio for both emissions and performance purposes. In the U.S., off-road engines are also regulated for emissions regardless of their size or equipment that they power. Generally, the off-road engines do not utilize oxygen sensors and computer controls to adjust fuel delivery by a closed loop system. In many products, emission compliance has dictated air-to-fuel ratio controls that are a delicate balance between being too rich and, therefore, out of compliance, or too lean, resulting in performance or durability problems.

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13 Id.

14 "Fuel Specifications in Latin America: Is Harmonization a Reality?" Henry Joseph Jr., ANFAVEA (Brazilian Vehicle Manufacturers Association), presented at the Hart World Fuels Conference, Rio de Janeiro, 21-23 June 2004.

The long term durability of emission control systems is a critical issue, with current U.S. federal and California emission standards requiring on-road vehicles to comply for up to 150,000 miles and off-road engines to comply for full useful life periods. If the control system of the vehicle was not designed to accommodate the leaning effect of ethanol, the vehicle's catalyst protection routine will be disabled. For off-highway engines, or older vehicles without closed loop systems, the enleanment influence can result in higher exhaust gas temperatures. This can cause thermal degradation of the catalyst over time, either through sintering of the precious metal wash-coat or damage to the substrate and can also degrade critical engine components such as pistons and exhaust valves.

ATTACHMENT 5

Preliminary Comments
on the report titled
"Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated," NREL/TP-540-43543 and ORNL/TM-2008/117, dated February 2009

Dr. Ron Sahu, Consultant to the Outdoor Power Equipment Institute (OPEI)

These comments focus exclusively on major adverse impacts observed during the tests performed on Small Non-Road Engines (SNRE), including lawn, garden and forestry products, like lawnmowers and trimmers.

I. THE TESTS DOCUMENT THE FOLLOWING MAJOR ADVERSE IMPACTS RESULTED FROM FUELS GREATER THAN 10% ETHANOL

A. Engine exhaust temperatures rose significantly. Significant rises in temperatures (exhaust, cylinder head, etc.) occurred on the order of 20 to 70 C from engines run on E0 compared to E20. For several categories, significant temperature rises resulted between E10 and E15. Additional heat generation has obvious implications on increased burn and fire hazards – considering the proximity of cut grass, wood chips and the operator to the engine's hot exhaust. However, the report does not delve into the implications of the additional heat and its ramifications on engine and equipment failure, personnel safety, increased fire hazards, or the inability to mitigate any of these hazards on millions of pieces of legacy equipment.

B. Risks to operators dramatically increased. The report recognizes that unintentional clutch engagement resulted on several tested products because of high idle speeds. Obviously significant risks are created when a chainsaw blade becomes engaged when the product should be idling. However, there is no discussion in the Report of this increased hazard. If anything, the mitigation proposed (i.e., adjustment of fuel air mixture enleanment) is unworkable and may even be illegal "tampering" under the EPA regulations. It is certainly not feasible to adjust carburetors on millions of legacy equipment that are already in use.

C. **Damage to Engines.** Both of the tested "Residential Handheld Engines" (engines B-3 and B-7 as shown in Figure 3.9, pp. 3-18) suffered total and complete failures and would not start or operate after running on E-15 fuel for 25 or less hours, which is less than half of their useful life.

D. **Operational Problems.** Many of the engines tested on mid-level ethanol suffered from erratic equipment operation, "missing" and stalling of engines, and power-reduction.

II. MISCHARACTERIZATION OF RESULTS IN THE EXECUTIVE SUMMARY

The Executive Summary does not accurately summarize the scope, results as well as uncertainties associated with the testing. Since most of the policy-makers will focus only on the Executive Summary, this could result in misinformed policies based on misleading conclusions.

There appear to be numerous, material inconsistencies in the manner in which the results are reported in the main body of the report versus in the Executive Summary, including the following examples:

A. The Executive Summary merely notes three handheld trimmers experienced higher idle speeds and unintentional clutch engagement. (See Sec. E.5.2). The report recognizes that this same problem could also occur on chainsaws. (See Sec. 3.2). The implications of unintentional clutch engagement in chainsaws and hedgeclippers (which are both examples of close-to-the-body, sharp-bladed equipment) are obvious and alarming; this substantial problem should have been fully addressed in the Executive Summary.

B. With regards to materials compatibility, the Executive Summary incorrectly concludes that "…no obvious materials compatibility issues were noted…" (see p. xix). In fact, the report itself recognizes that materials incompatibility (such as swelling of the elastomeric seat for the needle in the carburetor bowl) could be the cause of the engine stall for the Briggs and Stratton generator observed in the pilot study (see pp. 3-15). The report also states that: 1) "…various fuel-wetted materials in some small engines may not be compatible with all ethanol blends…" (see p. 3-9); and 2) "..materials compatibility issues…were not specifically characterized as part of the study…" (see p. 3-12).

C. Engines in the study experienced "unstable governor operation," "missing" and "stalling" when operating on E20 fuel, indicating unacceptable performance. (See Section 3.2.2). However, the Executive Summary omitted any discussion of these substantial problems.

D. Discussing emissions, the Executive Summary simply notes that HC emissions "generally decreased" and that combined HC+NOx emissions "decreased in most instances." (See p. xix). However, the report notes that while HC emissions generally decreased, they also increased in some engines. The net change in HC+NOx emissions ranged from -36% to +41% as reported in Sec. 3.2.2. It is important to note that for new engines, the net change in HC+NOx was often greatest in going from E0 to E10 and smaller in the other transitions (i.e., from E0 to E15 or E0 to E20). (See Table 3.7). For example, the numerical average for all engines shows that the HC+NOx reduction was -16.6% from E0 to E10; -13.5% from E0 to E15 and only -9.5% from E0 to E20. Since small engines are already capable of E10 operation and that fuel is already available, this data indicates that transitioning to E15 and E20 may actually increase HC+NOx from E10. (As a side note, what is actually measured as HC in the study is unclear since a FID was used for this purpose, uncorrected for any ethanol or aldehydes, as noted in the report).

III. DEFICIENCIES IN THE TESTING PLAN AND SCOPE

A. No emissions testing pertaining to evaporative emissions was conducted. Thus, all references to "emissions" means tail-pipe emissions from the engine. Evaporative emissions are now regulated by EPA for small engines and equipment and covered by the EPA "certification" program. Lack of evaporative emissions is a major omission.

B. The report does not contain any direct data on "materials compatibility" testing or results – i.e., involving the various fuels tested and the materials that may be exposed to these fuels and how they interact. Material compatibility is a significant concern with E15 and E20 fuels when used in small engines, leading not only to "operational issues" but also to durability, emissions, and safety impacts.

C. The report notes that the following fuels were used: E0, as well as splash-blended E10, E15, and E20. However, the report does not contain the actual ASTM specification of the blended fuels, including all relevant properties such as distillation cut point temperatures, etc. Table 2.2 of the report contains a few parameters of the blends. This is incomplete and a more compete fuel specification should be provided. The executive summary concludes that "…the different fuel characteristics of match-blended and splash-blended fuels were not expected to have a significant impact on temperature" or on durability. (See p. xviii). However, there is not any cited technical support for these statements. Similarly, there is no support for the observation that "...emission results...are not expected to vary significantly...between splash-blended and match-blended fuels." *Id.*

D. As the report notes, neither cold-start, nor warm-up testing was done, although these are two very common modes of operation for many categories of small engines. Additional performance tests that impact "operational issues" which should have been tested include: (i) acceleration; (ii) application performance; (iii) carburetor and breather icing; (iv) fuel consumption; (v) governor stability; (vi) load pick up; and (vii) vapor lock. Individual categories of small engines will likely have additional performance-related test requirements.

E. As the Executive Summary notes, the report presents "initial results...focused on identifying emissions or operational issues and measurement of several key engine temperatures..." (See p. xviii). It is not clear what is meant by "operational issues" or what quantitative surrogates and/or metrics were used to substitute for operational issues. It appears that erratic operation, high idle, stalling, etc. were used as evidence of operational issues. While these are undeniably evidence of operational issues, no testing appears to have been done on various actual equipment operational modes (as discussed later) so the full extent of operational issues has by no means been evaluated.

F. The report does not fully flesh out the issue and implications of irreversibility – i.e., once exposed to E15 and/or E20, performance is not restored simply by reverting to E0. In the case of the Poulan weedeater, it is noted that there were poor operations with E15 and E20 and that "normal operation could not be restored on E0." (See Section 3.2.2). This is significant. Actual users, when faced with operational problems with ethanol blended fuels, will, as common sense dictates, revert to E0. What they will find is that doing so will not "unring the bell" since the damage by the ethanol blends is not reversible simply by changing the fuel.

IV. UNREPRESENTATIVE AND LIMITED NUMBER OF TESTS CONDUCTED

A. The category of forestry, lawn and garden equipment includes a broad swath of equipment and engine types. Yet, the category has not been defined in the report so that the extent of test results presented can be judged in context. While noting that millions of products with small engines are sold each year (actually tens of millions), and that EPA certifies on the order of 900 engine emission families, the report does not cover the immense diversity of the category including: 1) the various engine and equipment types used, 2) the fuel delivery mechanisms, 3) the various sizes and functions of the equipment, 4) the constraints that the equipment operate under (such as close proximity to operators, as an example), and 5) many other characteristics. Engines in this product category utilize a wide variety of engine architecture including both single and twin cylinders, two cycle and four cycle combustion, ported and valve charge controlled, side valve and overhead valve orientations, with and without exhaust after-treatment, governed load and product load controlled, etc. The report should clearly qualify its findings are based on a tiny fraction of the diverse population of affected products.

B. The types and numbers of engines and equipment tested are inadequate to be representative of even the limited types of small engines that were the subject of testing. While practical constraints such as time and money will always constrain the amount of testing that can be done, the basis for choosing the engine and equipment – namely those found in "...popular, high sales volume equipment..." appears not to have been followed. For example, of the six pieces of equipment selected for the pilot study, four were generators. No chainsaws were tested, even though the OPEI had directly requested that they be included – because of their extreme operating conditions and sensitivity to mid-level ethanol. Also, it is explicable why only one residential hand-held engine would be tested, even though these are likely to be very sensitive to fuel changes. The report should provide the basis of selection rather than referencing unspecified EPA sources. One of the constraints also seems to have been the available laboratory equipment (i.e., lack of small engine dynamometers). This is clearly an inappropriate basis for constraining equipment selection, especially if the goal is to obtain data on the entire class of affected engines and products.

C. The report rightly notes the challenges associated with multi-cylinder engines – although characterizing these as being "more sensitive" is too vague. (See p. 3-11). It is unfortunate that while the study included one twin cylinder engine in the initial screening process, there were no twin cylinder engines included in the more in depth portions of the testing program. Particularly when the initial screening test clearly demonstrated significant influences of higher ethanol blends. A significant portion of the Class 2 (>225 cc) non-handheld engines produced each year are two cylinder engines. The omission of these engines in the expanded program is puzzling. The detailed test program should include engines and equipment that demonstrated any significant influence during the screening tests.

D. The limited number of tests conducted cannot provide assurances that the results presented have any statistical significance, where appropriate. In fact, no attempt is made to discuss results in terms of statistical significance. Nor are such issues discussed in support of the design of the test matrix itself. For example, no pair-wise tests were run or results reported even though those opportunities were available even with the limited equipment selection.

E. The manner in which the tests were run makes it difficult to separate the effects of engines, fuels, and aging. For example, the full-life tests do not allow the ability to distinguish between fuel-driven and engine-driven causes since only one engine was tested on each fuel. In the pilot study, the effects of the fuel and aging are similarly hard to separate. These types of issues could have been avoided with better test planning.

V. OTHER COMMENTS

A. The comments are preliminary because not all of the test data discussed in the report are included. Specifically, backup test data for all tests conducted by the Dept. of Energy (NREL and ORNL) and its contractors (TRC) still need to be provided.

B. The report notes that the test plan was developed with close consultation involving, among others, "...US automobile companies, engine companies, and other organizations..." It would be helpful to have details of all the companies and individuals consulted in an Appendix to the report.

C. The report does not separately discuss the comments of the peer reviewer(s) and what changes were made to the draft report as a result. While the Acknowledgements note that the peer review panel was led by Joseph Colucci, the report does not contain a list of all peer reviewers used, what portions of the report were peer reviewed by whom, and the necessary vitae for the reviewers. This should be included.

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<u>EXPERIENCE SUMMARY</u>

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Dr. Sahu has over sixteen years of experience in the fields of energy, environmental, mechanical, and chemical engineering including: program and project management services; design and specification of air pollution control equipment; soils and groundwater remediation; combustion engineering evaluations; energy studies; multimedia environmental regulatory compliance (involving statutes and regulations such as the federal CAA and its Amendments, Clean Water Act, TSCA, RCRA, CERCLA, SARA, OSHA, NEPA as well as various related state statutes); transportation air quality impact analysis; multimedia compliance audits; multimedia permitting (including air quality NSR/PSD permitting, Title V permitting, NPDES permitting for industrial and storm water discharges, RCRA permitting, etc.); multimedia/multi-pathway human health risk assessments for toxics; air dispersion modeling; and regulatory strategy development and support including negotiation of consent agreements and orders.

He has over fifteen years of project management experience and has successfully managed and executed numerous projects in this time period. This includes basic studies and applied research projects, design projects, regulatory compliance projects, permitting projects, energy studies, risk assessment projects, and projects involving the communication of environmental data and information to the public.

He has provided consulting services to numerous private sector, public sector, and public interest group clients. His major clients over the past sixteen years include the Outdoor Power Equipment Institute and its various members who are manufacturers of small engines and equipment, various steel mills, petroleum refineries, cement companies, aerospace companies, power generation facilities, spa manufacturers, chemical distribution facilities, and various entities in the public sector including the EPA, U.S. Dept. of Justice, California DTSC, and various municipalities. Dr. Sahu has performed projects in over 48 states, numerous local jurisdictions, and internationally.

In addition to consulting, Dr. Sahu has taught and continues to teach numerous courses in several southern California universities including UCLA, UC Riverside, and Loyola Marymount University for the past fourteen years. In this time period, he has also taught at Caltech and USC.

Dr. Sahu has and continues to provide expert witness services in a number of environmental areas discussed above in both state and federal courts as well as before administrative bodies.

ATTACHMENT 6

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High Ethanol Fuel Endurance:

A Study of the Effects of Running Gasoline with 15% Ethanol Concentration in Current Production Outboard Four-Stroke Engines and Conventional Two-Stroke Outboard Marine Engines

June 16, 2010 – June 30, 2011

David Hilbert
Mercury Marine
Fond du Lac, Wisconsin

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Subcontract Report
NREL/SR-5400-52909
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NREL Technical Monitor: Keith Knoll

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High Ethanol Fuel Endurance

A study of the effects of running gasoline with 15% ethanol concentration in current production outboard four-stroke engines and conventional two-stroke outboard marine engines.

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Executive Summary

Objective:

The objective of this work was to understand the effects of running a 15% ethanol blend on outboard marine engines during 300 hours of wide-open throttle (WOT) endurance – a typical outboard marine engine durability test. For the three engine families evaluated, one test engine each was endurance tested on E15 fuel with emissions tests conducted on both E0 and E15 fuel, while a second control engine was emissions and endurance tested on E0 fuel for each engine family.

Summary of Results:

Results are based on a sample population of one engine per test fuel. As such, these results are not considered statistically significant, but may serve as an indicator of potential issues. More testing would be required to better understand the potential effects of E15.

9.9HP Carbureted Four-Stroke:

- The E15 engine exhibited variability of HC emissions at idle during end-of-endurance emissions tests, which was likely caused by lean misfire.
    - Both the E0 control engine and E15 test engine ran leaner at idle and low speed operation at the end of endurance testing compared with operation at the start of the test.
    - The trend of running lean at idle coupled with the additional enleanment from the E15 fuel caused the E15 engine to have poor run quality (intermittent misfire or partial combustion events) when operated on E15 fuel after 300 hours of endurance.
    - CO emissions were reduced when using E15 fuel due to the leaner operation, as expected for this open-loop controlled engine.
- The E15 engine exhibited reduced hardness on piston surfaces based on post-test teardown analysis.
    - The exhaust gas temperature increased 17°C at wide open throttle as a result of the leaner operation when using E15 fuel. Higher combustion temperatures may have caused observed piston hardness reductions. Lack of pre-test hardness measurements prevented a conclusive assessment.
- Several elastomeric components on the E15 engine showed signs of deterioration compared with the E0 engine.
    - Affected components were exposed to E15 fuel for approximately 2 months; signs of deterioration were evident.

300HP Four-Stroke Supercharged Verado:

- The E15 engine failed 3 exhaust valves close to the end of the endurance test.
    - Metallurgical analysis showed that the valves developed high cycle fatigue cracks due excessive metal temperatures.
- The pistons on the E15 engine showed indications of higher operating temperatures compared to the E0 engine's pistons as evidenced by the visual difference in carbon deposits.
- The E15 engine generated HC+NOx values in excess of the Family Emissions Limit (FEL) when operated on E15 fuel, but did not exceed that limit when operated on E0 emissions certification fuel.

   - The primary contributor to this increase in exhaust emissions was NOx due to enleanment caused by the oxygenated fuel.

   - CO emissions were reduced when using E15 fuel due to leaner operation, as expected for this open-loop controlled engine.

200HP EFI 2.5L Two-Stroke:

- The 200 EFI two-stroke engine showed no signs of exhaust emissions deterioration differences due to the fuel.

   - The E15 fuel caused the engine to run lean resulting in reduced HC and CO emissions. NOx was of little concern on this type of engine since NOx accounted for less than 2% of the total regulated HC+NOx emissions.

- The E15 engine failed a rod bearing at 256 hours of endurance, which prevented completion of the 300 hour durability test.

   - Root cause of the bearing failure was not determined due to progressive damage.

   - More testing would be necessary to understand the effect of ethanol on oil dispersion and lubrication in two-stroke engines where the fuel and oil move through the crankcase together.

4.3L V6 EFI Four-Stroke Catalyzed Sterndrive:

- Since E15 fuel was readily available in the test facility and an engine equipped with exhaust catalysts was on the dynamometer, emissions tests were conducted on a 4.3L V6 sterndrive engine to better understand the immediate impacts of ethanol on this engine family.

   - At rated speed and load (open-loop fuel control) E15 caused exhaust gas temperatures to increase by 20°C on average and the catalyst temperatures to increase by about 30°C.

   - More rapid aging of the catalyst system occur due to the elevated catalyst temperature when considering the high load duty cycle typically experienced by marine engine applications.

Conclusions and Recommendations:

Several issues were discovered in this study from an exhaust emissions and an engine durability standpoint as a result of running E15 fuel in outboard marine engines. Run quality concerns were also identified as a result of the lean operation on the carbureted engine.

Additional investigation is necessary to more fully understand the observed effects and to extrapolate them to all types of marine engines over broader operating conditions. Effects on operation at part load, transient acceleration/deceleration, cold start, hot restart, and other driveability-related concerns need to be evaluated. This test program was mainly testing for end-of-life durability failures, which would not likely be the first issues experienced by the end users. A customer would likely be affected by run quality/driveability issues or materials compatibility/corrosion issues before durability issues. The wide range of technology used in marine engines due to the wide range of engine output will complicate this issue (Mercury Marine produces engines from 2.5HP-1350HP).

More testing is needed to understand how ethanol blends affect lubrication systems in two-stroke engines that have fuel and oil moving through the crankcase together. Crankcase oil dispersion is the only mechanism by which two-stroke engines of this architecture provide lubrication at critical interfaces such as bearings and cylinder walls. Ethanol may have an effect on the dispersion or lubricity of the oil.

A better understanding of how long term storage affects ethanol blends in marine fuel systems would require more real-world testing. Marine vessels often go through long periods of storage that could affect the fuel systems given the fact that the ethanol portion can absorb water when exposed, especially in humid areas near saltwater.

Introduction

Project Background:

This project was a cooperative effort to assess the feasibility for marine engines of increasing the allowable ethanol concentration in gasoline above the current legal limit of 10%. Specifically, a 15% ethanol / 85% gasoline fuel blend (E15) was tested in current production and legacy outboard marine engines. Gaseous exhaust emissions and engine durability were assessed on a typical durability test cycle. Three separate engine families were evaluated. A 200HP EFI two-stroke engine was chosen to represent legacy product. A 9.9HP carbureted four-stroke engine and a 300HP supercharged EFI four-stroke engine represented current product. Two engines were tested from each family. One was operated on E15 fuel and the other was operated on E0 gasoline. Emissions data from each engine were obtained before, in the middle of, and after durability testing.

Summary of Marine Engine Considerations:

Marine engines require unique considerations when altering the fuel supplied to operate the engine. Considering these engines are frequently used in remote locations (offshore fishing for example), it is critical to ensure that the fuel does not cause or contribute to an engine malfunction. Changes in fuel formulations and the resulting effects on marine engine operability are of high importance.

Outboard marine engines span a large range of rated power output and technology which yields significant complexity when trying to understand the effects of changing the fuel supplied to the engine. When all of the typical Mercury production engines and the Mercury Racing products are included (inboards and outboards), engines from 86cc, 2.5HP up to 9.1L 1350HP twin turbo configurations are produced. Mercury outboards (the focus of this study) range in output and design from the 2.5HP splash lubricated carbureted four-stroke engines to 350HP supercharged EFI four-stroke and 300HP direct fuel injected two-stroke engines. If sterndrive/inboard engines are considered, the technology list gets even broader. The non-racing sterndrive products range from 135HP carbureted 4 stroke to 430HP closed-loop catalyzed EFI 4 stroke with onboard diagnostics. The sales volumes of marine engines may be much smaller than automotive or small offroad utility engines, but the range of power (nearly 3 orders of magnitude) and the range of available technology of marine engines is much wider than these other categories individually.

The marine application requires an engine that has high power density and remains durable at high speeds and loads. It is important to minimize the amount of weight added to the vessel from the powertrain to maximize the payload and minimize drag. Boat hull drag is considerable at typical boat operating speeds resulting in high engine speeds and loads for extended periods. The result of these factors leads to engines which are high performance and made from premium materials. Changing the fuel specification must be carefully considered to assure that durability is not sacrificed. Figure 1 illustrates the power density of the Verado engine (the 300HP supercharged EFI engine family used in this study) compared to automotive engines that were contemporary when the Verado engine was introduced for the 2005 model year. Figure 2 shows a relative comparison of the vehicle load curves of a boat with a planing hull to an automobile. The likelihood of experiencing problems as a result of extended operation at or near WOT are far more pronounced on a marine engine than an automotive engine due to the great difference in vehicle load curves.

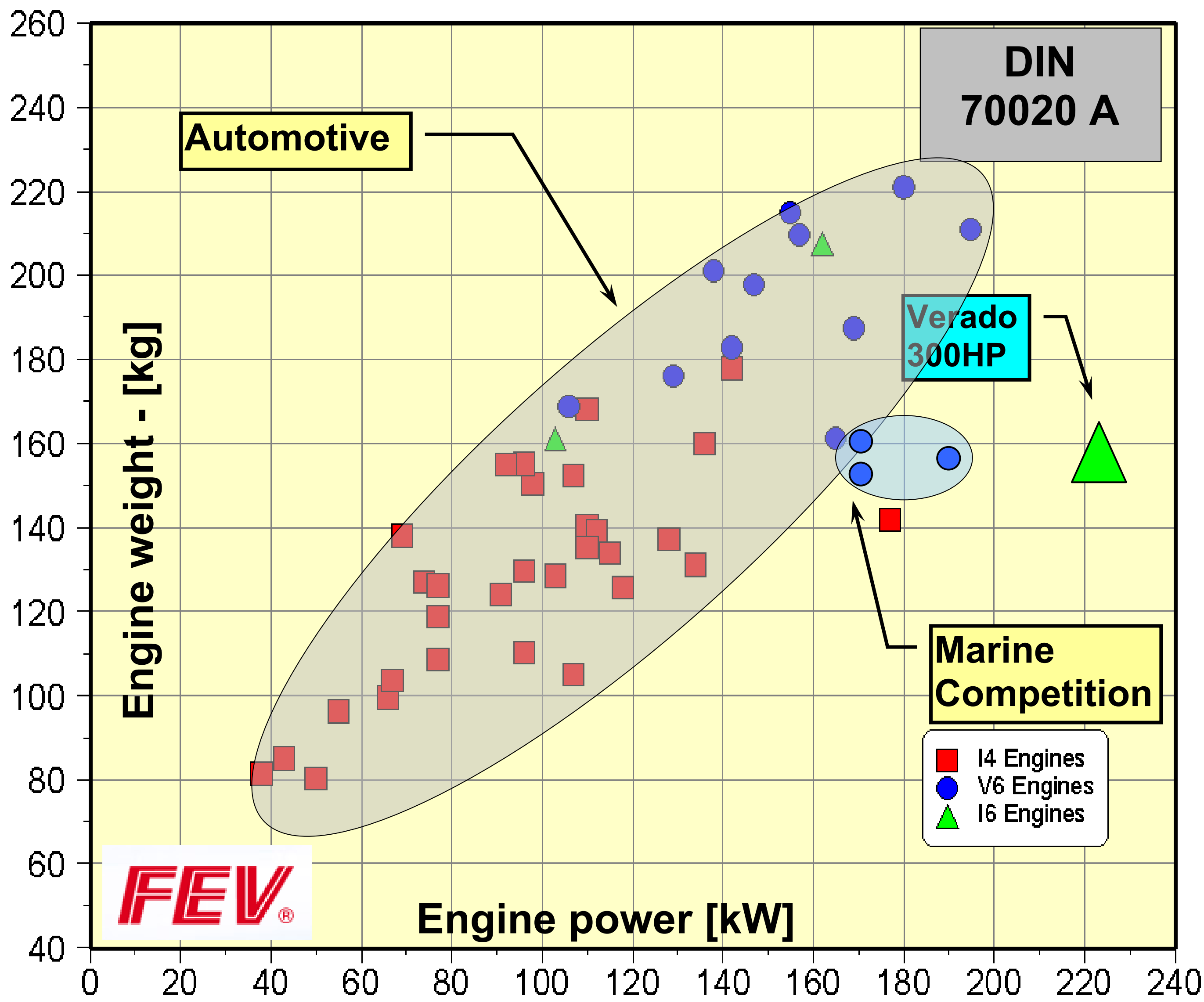


Figure 1: Power to Weight Comparison, Scatter Band Data Provided by FEV (FEV Motorentechnik GmbH)[1]

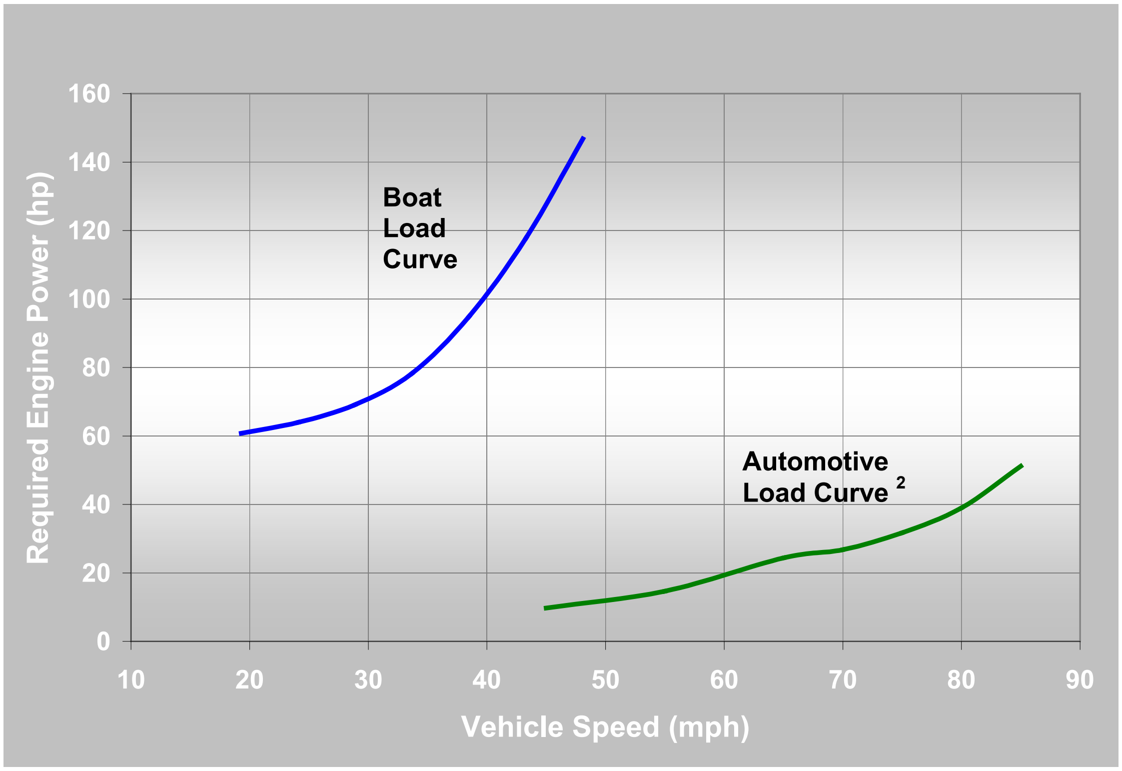


Figure 2: Example Load Curve Comparison (Automotive data – source 2, boat load data – internal Mercury source)

Investigation Details

Statement of Problem:

Procedure:

The engine testing process began by preparing each engine. This included instrumentation of the test engines as well as performing some basic checks (varied by engine type). The instrumentation process included installation of an exhaust emissions probe that met the requirements of the EPA 40 CFR Part 91 regulations.

Each engine was rigged onto an appropriate dynamometer and a break-in process was performed. The break-in consisted of increasing speed and load settings for approximately 2.5 hours total duration and was performed on E0 gasoline for all engines. This was followed by a power run to determine the wide open throttle (WOT) performance of each engine. The power run was performed on E0 gasoline on all engines and also on E15 fuel for only the E15 test engines. The power run included speed points from 2000RPM up to the maximum rated speed of the engine.

Once the WOT performance was checked, emissions testing was performed using reference-grade E0 gasoline (EEE fuel: EPA Tier II emissions reference grade fuel). The emissions tests were done in triplicate to check repeatability and were run in accordance with the EPA requirements set forth in 40 CFR Part 91. Emissions tests were also performed on the E15 engines in triplicate using the E15 test fuel. Although this E15 test fuel was not blended from the reference-grade E0 gasoline, these tests provide some comparison of exhaust emissions between E0 and E15 while minimizing engine-to-engine variability.

Following the above emissions checks, each engine was prepared for the durability testing. This included doing a basic visual inspection as well as some general engine power cylinder integrity checks (example: compression test and cylinder leak-down). These integrity checks were also repeated at the durability mid-point and end-of-life test point as well.

The first half of the durability test was then performed. Each engine was rigged in Mercury's Indoor Test Center, which consisted of large endurance test tanks, air supply systems, and data acquisition systems. Each engine was fitted with the appropriate propeller to operate the engine approximately in the midpoint of the rated speed range at wide open throttle. The engine instrumentation was continuously monitored and the data was recorded for the duration of the endurance test. Operational shutdown limits were placed on critical channels (min/max engine speed, max coolant temperature, etc) to monitor the health of the engine for the entire durability test period. Periodic maintenance was performed on each engine (as appropriate for the engine type: oil level checks and changes, accessory drive belts, etc). This maintenance was performed in an accelerated manner as compared with typical customer maintenance intervals since the durability testing causes accelerated wear as compared with typical customer use. These protocols are typical of those used by Mercury for any durability test.

Once the first half of the durability testing was completed, each engine was rigged on the dynamometer again. Emissions tests on the appropriate fuel(s) were performed according to the procedures described above. The tests were again performed in triplicate to be able to evaluate repeatability. Each engine also got a visual inspection and the general engine power cylinder integrity checks before being returned to durability testing.

After the midpoint emissions testing was completed, each engine was returned to the Indoor Test Center endurance tank to complete the second half of the durability testing. The testing was performed in the same manner as the first half of the durability portion.

When the durability testing was complete, each engine was returned to the dynamometer for post-durability emissions tests on the appropriate fuel(s). A post-endurance WOT performance power run was also performed to compare with the pre-durability power run.

Finally, after all running-engine tests were completed, each test engine underwent a complete tear-down/disassembly and inspection. This inspection included checks and measurements to assess the degree of wear, corrosion issues, cracks, etc. on power cylinder components. Emphasis was placed on components that would be at risk due to the differences in the fuels (exhaust valves due to exhaust gas temperature differences, for example).

Test Engine Description:

The engines used for this testing were all built as new engines on the production line and were randomly selected. They were not specially built or hand-picked. The choice of engine families to include in this program was based on representing a wide range of technology, a wide range of power output, and a significant annual production volume. The final engine family selection was approved by the Technical Monitor at NREL. Two 4-stroke engine families were selected to represent current production engines. A two-stroke engine family was selected to represent “legacy” products. Table 1 summarizes each test engine configuration.

The 9.9HP four-stroke engine is used on a wide range of applications from small fishing boats, inflatable boats, and as a “kicker” engine. A “kicker” engine is an auxiliary engine used for low speed boat maneuvering while fishing on a large boat which includes a larger engine (150+HP) for the main propulsion. The 9.9HP engine is considered a portable engine. It was selected for this testing due to high sales volume and the fact that it represents the typical architecture for many of Mercury’s small carbureted four-stroke offerings. It should be noted that the settings for the carburetors on both of the 9.9HP test engines were set and sealed at the carburetor manufacturer. They were not tampered with by any Mercury personnel and were run just as they would if they were used by the end customer. The only adjustment allowed was the idle throttle stop to set the idle speed, which is the only adjustment a customer has access to.

The Verado engine is considered the “flagship” outboard product at Mercury Marine. The non-Racing version used in this study is available in power outputs ranging from 200-300HP. These engines are used on boats with single, dual, triple, and even quad engine installations ranging from multi-engine offshore fishing boats & US Coast Guard patrol boats, high speed bass boats, all the way to commercial fishing vessels and ferry boats. The supercharged 300HP Verado was selected for testing due to the high performance nature of its design and the demands of this market segment. The Verado engines had an open loop electronic fuel injection system with no user adjustment possible.

The 200HP EFI two-stroke engine represents the “legacy” two-stroke products. The 2.5L platform has been the basis for carbureted, crankcase fuel injected (which is the case for the test engines used), and direct cylinder injection models. The platform has roots that can be traced back to the 1970’s. This engine was selected for testing because of the large number of engines that have been built off of this platform over the last several decades and that it represents the typical architecture for a variety of Mercury’s two-stroke product. An engine configuration with an EFI fuel system was selected to improve consistency in testing. The 2.5L 200HP EFI engine had an open loop electronic fuel injection system with no user adjustment possible.

Table 1: Test Engine Specifications

Engine Family	9.9HP Four-Stroke	Verado	200HP EFI
Gas Exchange Process	Four-Stroke	Four-Stroke	Two-Stroke
Power Rating at Prop	9.9HP	300HP	200HP
Cylinder Configuration	Inline 2 Cylinder	Inline 6 Cylinder	60 Degree V-6 Cylinder
Displacement	0.209 Liter	2.59 Liter	2.51 Liter
Fuel Induction System	Single Carburetor w/Accelerator Circuit, 2 Valve per Cylinder, Single Overhead Cam	Supercharged Electronic Fuel Injected 4 Valve per Cylinder, Dual Overhead Cam, Electronic Boost Control, Electronic Knock Abatement Strategy	Electronic Fuel Injected with Oil Injection, Loop Scavenged Porting, Crankcase Reed Induction, Electronic Knock Abatement Strategy
Dry Weight	108 lbs / 49 kg	635 lbs / 288 kg	425 lbs / 193 kg
Fuel Octane Requirement	87 Octane R+M/2 Minimum Required	92 Octane R+M/2 Recommended, 87 Octane R+M/2 Minimum Required	87 Octane R+M/2 Minimum Required

Test Fuel Description:

The fuels used in the endurance testing were intended to be representative of typical pump-grade fuels that could be commonly available to the general consumer. The primary factors in sourcing the E15 test fuel were consistency of fuel properties for the duration of testing, consistency of ethanol content at 15%, octane performance that met specific requirements for each test engine, and a representative distillation curve to match charge preparation characteristics. The E15 test fuel was splash blended by our fuel supplier in one batch to ensure consistency throughout testing. The E0 and E15 endurance fuels were sourced from different suppliers; as such there were likely differences in the additive packages (including the concentration of additives) of the fuels. Since the primary duty cycle was wide open throttle endurance, the additive package differences likely had little influence on the test. Since the Verado engine had a premium fuel recommendation, the E15 fuel was blended at a target of 91 octane [R+M]/2. The blend stock used was a typical pump-grade fuel that the supplier used for retail distribution. The E0 fuels used for the endurance testing were also typical pump-grade fuels that the fuel supplier had available for distribution. Both a Regular (87 octane [R+M]/2) and a Premium (91 octane [R+M]/2) fuel supply were maintained at Mercury for testing on this program and all other internal Mercury test programs. The emissions tests on E0 fuel were all performed using EPA Tier II EEE fuel sourced from specialty fuel manufacturer Johann Haltermann Ltd.

Samples of several of the test fuels were sent to outside laboratories for analysis. The parameters that were considered were: the distillation curve (ASTM D86)[3], Research and Motor Octane (ASTM D2699[4] and D2700[5]), density, and API gravity. In addition, NREL measured ethanol content via the Grabner IROX 2000 Gasoline Analyzer and ASTM D5501[6] for the E15 fuel. The Grabner IROX 2000 measures ethanol via infrared spectroscopy (per ASTM 5845[7]) and is valid in the range of 0 – 25% ethanol. The ASTM 5501[6] method uses gas chromatography and is only valid for high levels of ethanol (93% to 97% ethanol); it was used here only as a reference. In-house fuel samples were also taken and analyzed on the Petrospec GS-1000 analyzer. This analyzer was used to estimate the octane and measure the oxygenate concentration. Like NREL's Grabner IROX 2000, the Petrospec GS-1000 operates on the infrared spectroscopy concept and determines the ethanol concentration (up to 15%) per ASTM D5845[7]. The results from the Petrospec machine were used as reference values only, primarily for quality control.

Table 2 shows the various measurements made on the test fuels from the different measurement laboratories. The majority of the parameters were within expected ranges for the tolerance of the measurements used. The ASTM D5501[6] procedure used at NREL showed that the ethanol concentration was 18%. The results from the 2 infrared spectroscopy measurements from both NREL and Mercury showed concentrations of approximately 14%. The results from the 2 methods bracket the target concentration of 15%, which was the actual concentration that the fuel was blended to at the fuel supplier. Only one sample of E15 was analyzed, which was valid since all of the E15 fuel was blended in one batch. The data sets from the 87 octane bulk/pump fuel and the 91 octane bulk/pump fuel used on endurance, and the data from the EEE were from one load of fuel of the multiple loads of fuel of each type used during the duration of the testing.

Table 2: Fuel Analysis Results

Fuel Analysis		**E15 Fuel**	**EEE**	**87 Bulk Fuel**	**91 Bulk Fuel**	**91 Bulk Fuel Repeat**
Sample Date		**10/21/2010**	**10/8/2010**	**10/15/2010**	**10/15/2010**	**2/10/2011**
Fuel Analysis Performed at Outside Laboratory						
Research Octane (ASTM D2699)	RON	95.7	97.2	89.6		93.4
Motor Octane (ASTM D2700)	MON	86.3	88.5	84.6		87.5
[R+M]/2	AKI	91.0	92.9	87.1		90.45
Density @ 15.5C	kg/L	0.752	0.744			
API Gravity	°API	56.5	58.7			
Fuel Analysis Performed at NREL						
Ethanol Content (ASTM D5501)	%	18+/-1%				
Ethanol Content (IROX analyzer)	%	14%				
Fuel Analysis Performed at Mercury Marine						
Petrospec analyzer (E15 data ave. of 2 samples)						
Ethanol Content	%	14.1%	0	0	0	
RON	RON	95.7	95.8	89.4	92.9	
MON	MON	84.7	87.7	83.3	87.2	
[R+M]/2	AKI	90.2	91.7	86.4	90.1	
Reid Vapor Pressure (Mercury analysis)	PSI	8.5	9.0	10.8	10.7	

The distillation curves for the various test fuels were also measured. The results can be seen in Figure 3 below. The data shown in Figure 3 were from the actual test fuels used in this testing. The distillation curve from the E15 fuel showed a large step change in the region of the boiling point of ethanol, as was expected.

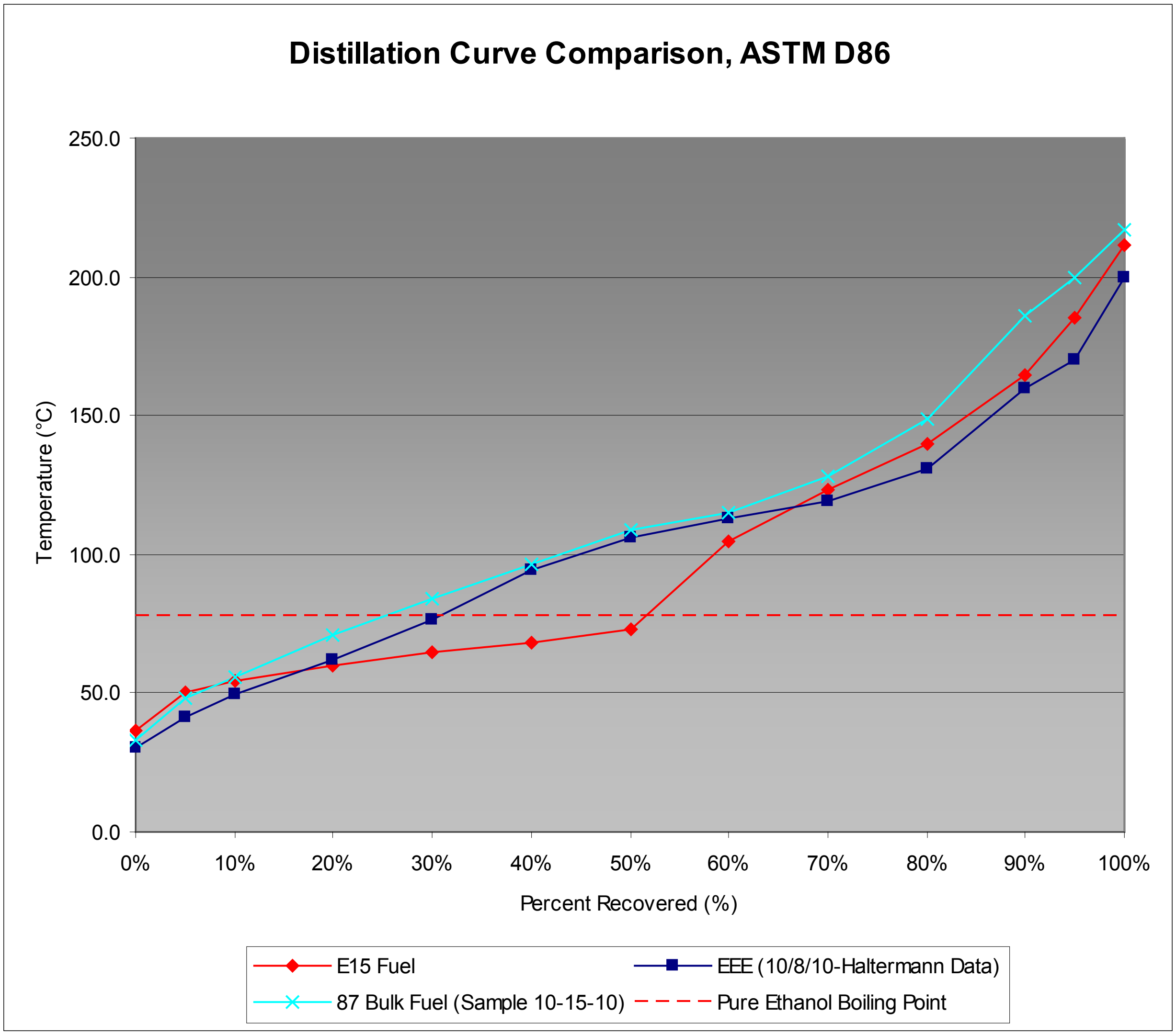


Figure 3: Distillation Curves of Test Fuels

Engine Testing Results

9.9HP Four-Stroke:

Endurance Test Results

The endurance testing on the 9.9HP engine family precipitated no significant failures. There were no incidents related to the test fuels reported on either engine. There were several parameters measured at the start, middle, and end of test to check the general health of the engine during the course of the endurance test. These included cranking compression, power cylinder leakdown, cam timing, and valve lash. All of these parameters remained relatively unchanged through the course of testing within the repeatability of the measurement techniques used. Several fuel-effect differences between the test engines, however, were discovered during the end of test teardown and inspection. These differences are summarized in the section below.

Emissions Testing Results

A summary of the emissions results are shown in Figure 4 below, with the 5 mode total weighted specific HC+NOx values plotted on the Y axis and the amount of endurance time on each engine plotted on the X axis. Each data point on the curve represents the average emissions value of the 3 emissions tests performed at each interval. The error bars represent the minimum and maximum values of the 3 emissions tests at each interval. The dashed yellow line shows the data from the E0 engine (serial number 0R364814). The solid red and blue lines show the emissions data from the E15 engine (serial number 0R352904) using E15 and E0 (EEE) fuels, respectively. Figure 4 shows that the E0 engine had significantly lower emissions than the E15 engine when run on the same fuel. After reviewing the history of the emissions audits on this engine family dating back to its introduction in 2005, both of these engines were within normal production variability.

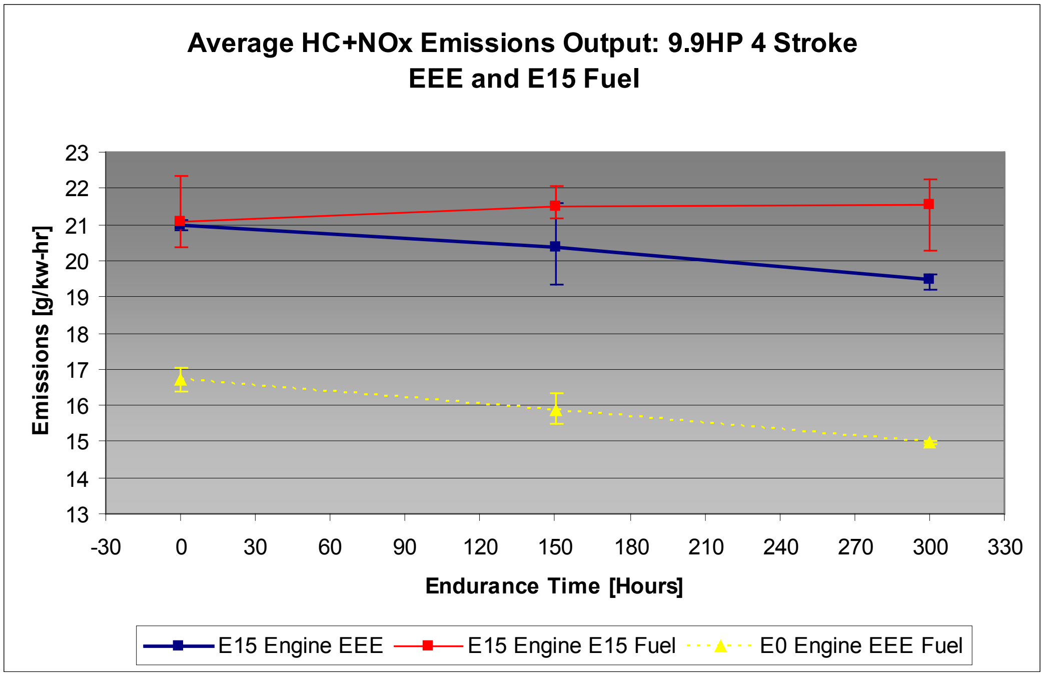


Figure 4: 9.9HP Four-Stroke HC+NOx Emissions Results Summary

In order to better understand the emissions output, the HC, NOx, and CO constituents were broken out and plotted separately in Figures 5, 6, and 7 respectively. The values for each constituent are the five mode totals of each.

Figures 5 and 6 show that the HC emissions predominantly defined the overall trends and variability in the total HC+NOx trends seen in Figure 4. The NOx data shown in Figure 6 had low test-to-test variability and the values were relatively flat (perhaps slightly declining for the E15 engine on E15 fuel) over the life of both engines.

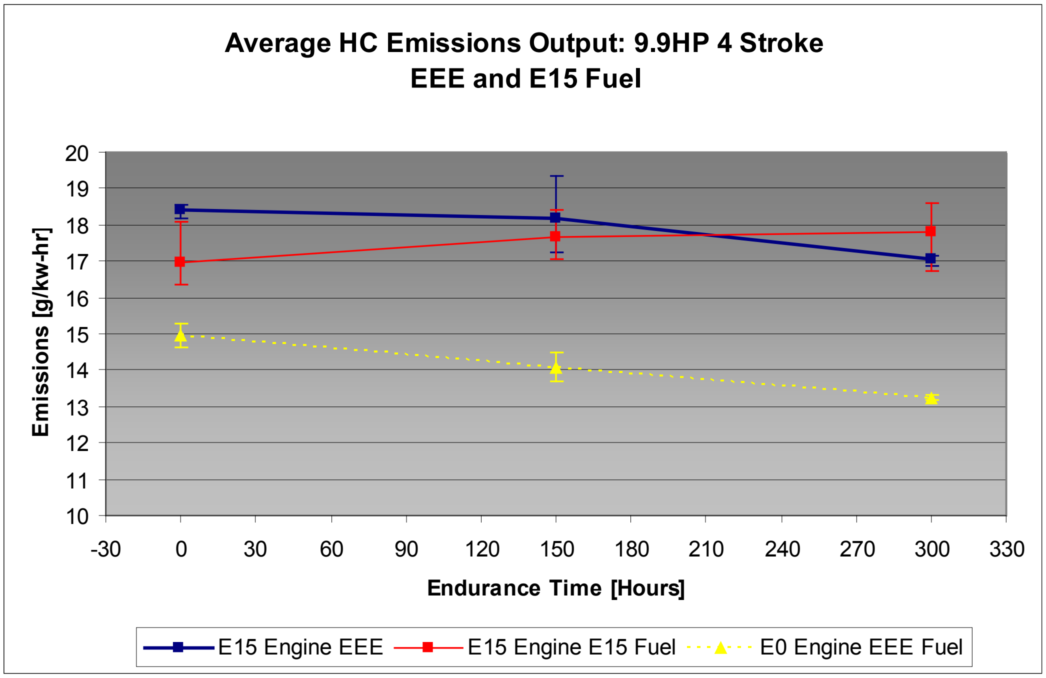


Figure 5: 9.9HP Four-Stroke HC Emissions Results Summary

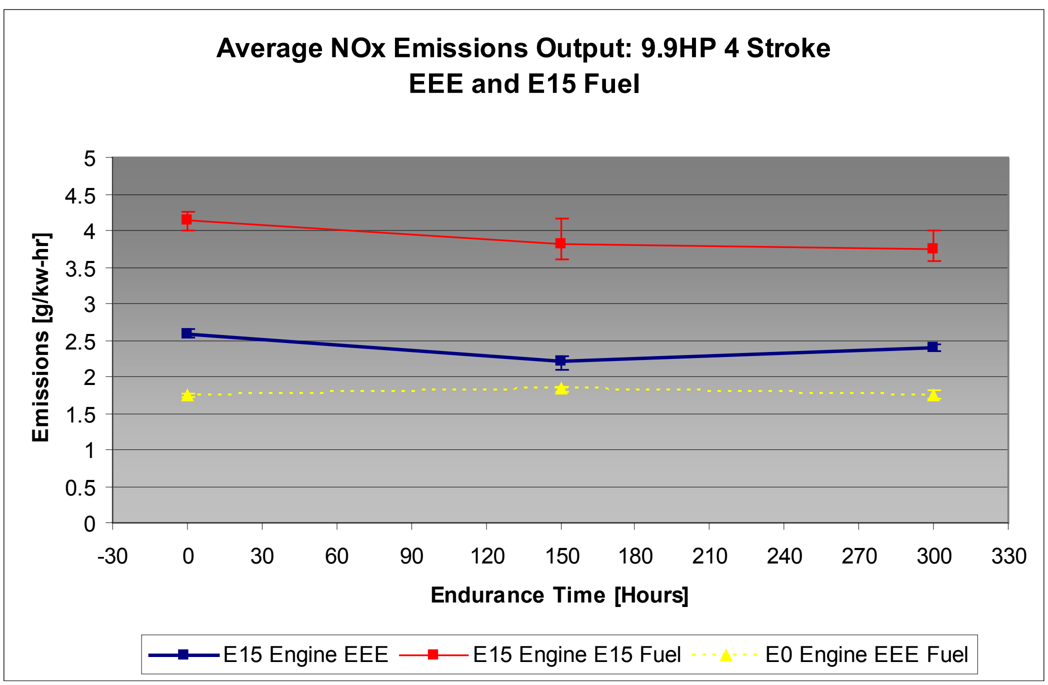


Figure 6: 9.9HP Four-Stroke NOx Emissions Results Summary

There was a general downward trend in CO over endurance time for the E15 engine on both fuels. The E0 showed some reduction in CO between 0 and 150 hours and remained relatively flat from 150 to 300 hours. The reduction in CO would suggest that the engines were running leaner since the primary driver for changing the CO emissions is typically the equivalence ratio.

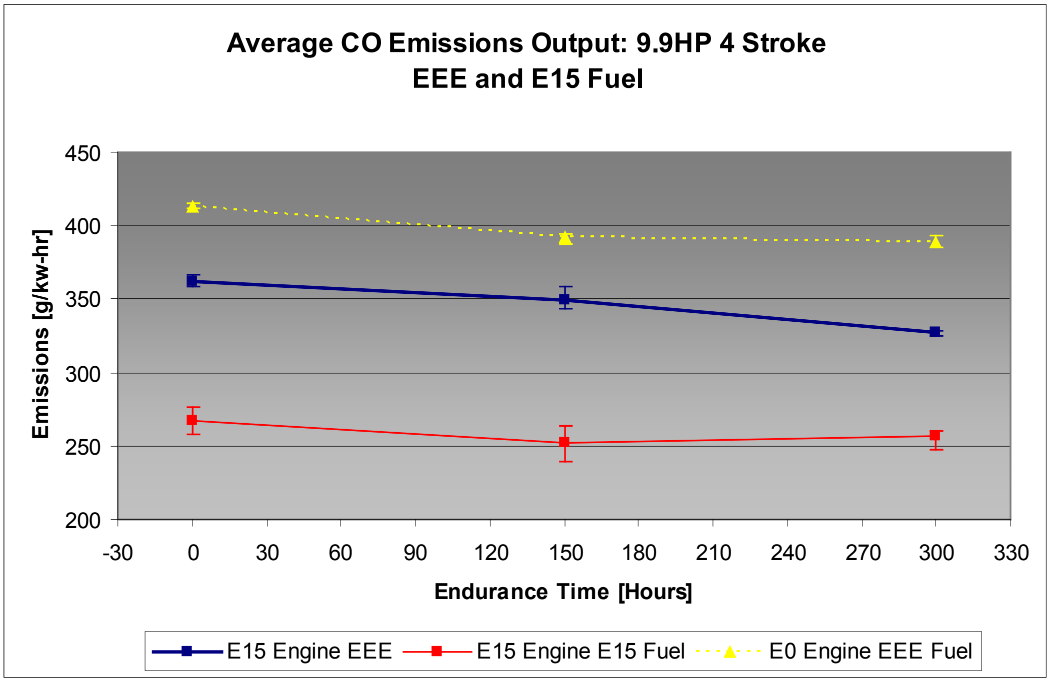
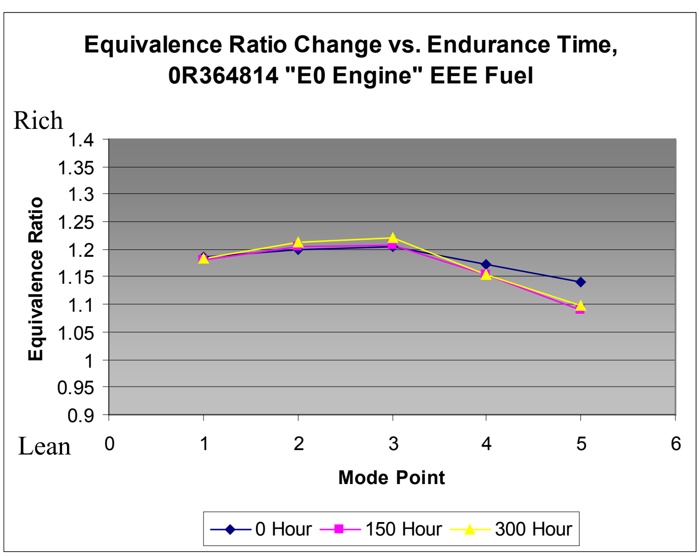
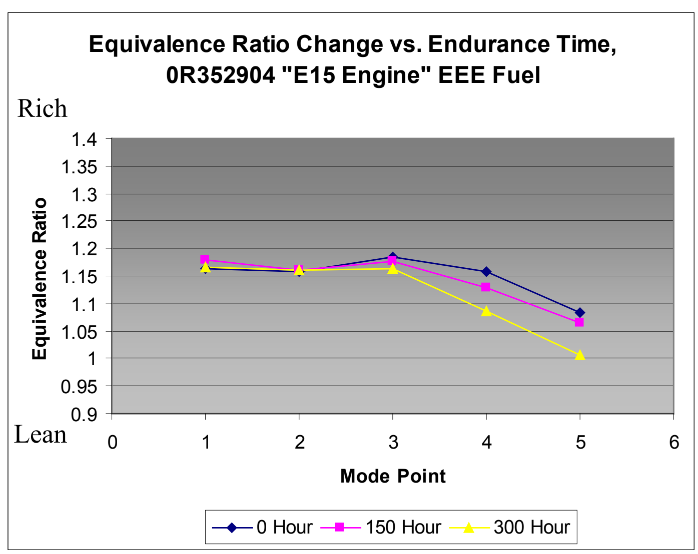


Figure 7: 9.9HP Four-Stroke CO Emissions Results Summary

The enleanment over time trend predicted from the CO data in Figure 7 was confirmed in Figures 8 and 9 for both the E0 and E15 engines operated on EEE-E0 fuel in both cases. The interesting thing to note was that the primary modes that became leaner were modes 4 and 5. During the end of test inspection on both engines, wear on the throttle plates was found on the sides where the throttle shafts went through the carburetor bodies. The wear caused gaps around the throttle plates which allowed excess air to enter the engines at low throttle opening positions (high manifold vacuum), which included Modes 4 and 5. The amount of wear found was considered normal for the amount of endurance time the engines experienced and was found on both engines.

It should be noted that the E15 engine ran leaner than the E0 engine when operated on EEE-E0 fuel, as can be seen in Figures 8 and 9 from a comparison of the "0 hour" equivalence ratios of both engines. This difference in equivalence ratio is considered to be in the normal production variability of this carbureted engine family.





Figures 8 & 9: Change in Equivalence Ratio vs. Endurance Time-EEE Fuel on E0 engine and E15 Engine

In addition, the equivalence ratio vs. endurance time data was plotted for the E15 engine when operated with E15 fuel in Figure 10. The graph shows the same trend of leaner operation vs. endurance time for Modes 4 and 5, as expected. However, when looking at the equivalence ratio values generated by the engine at Mode 5, it is clear that the engine ran very lean after 300 hours of endurance. This lean operation was the result of the inherent enleanment from the E15 fuel coupled with the trend of the engine to operate leaner with more endurance time due to the throttle plate wear.

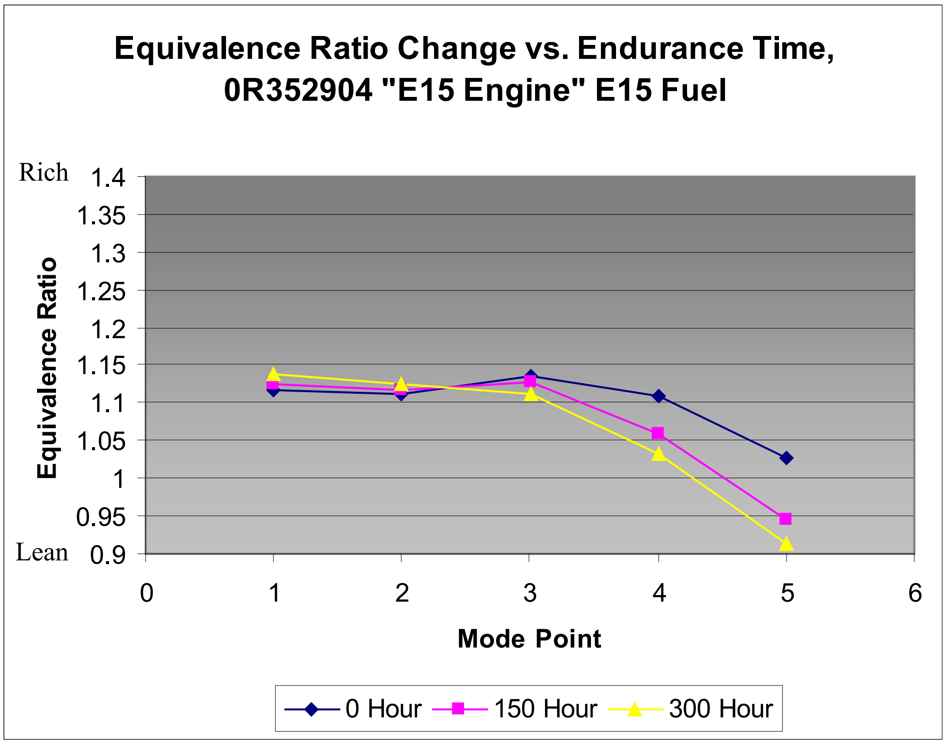
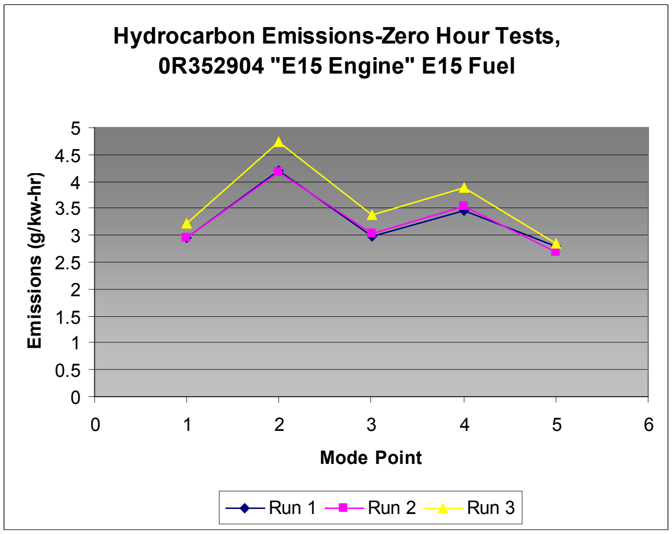
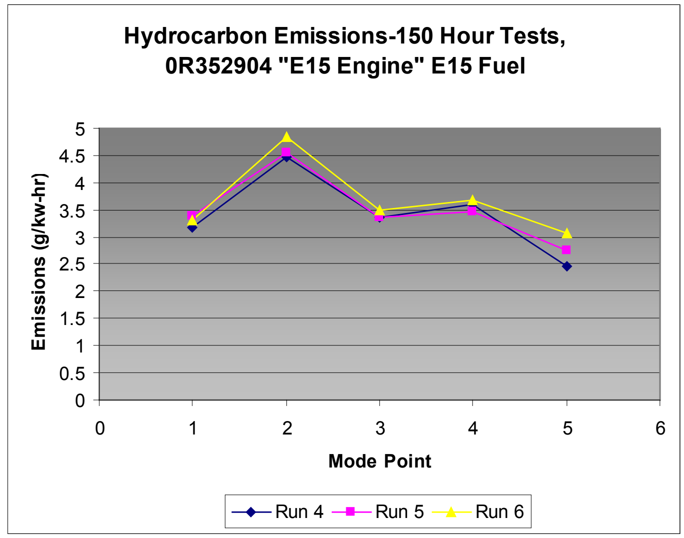
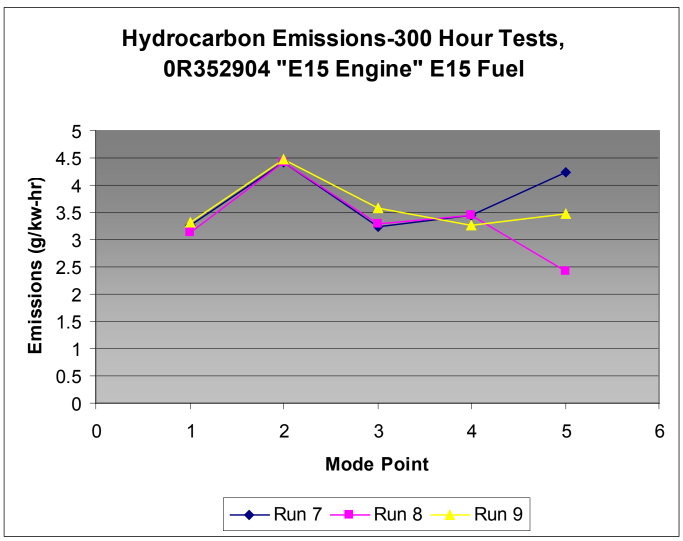


Figure 10: Change in Equivalence Ratio vs. Endurance Time-E15 Fuel on E15 Engine

It is clear that both engines ran leaner with more endurance time, yet the HC emissions increased (on average) for the E15 engine using E15 fuel (see Figure 5). To get more understanding, the hydrocarbon emissions results from each individual emissions test were plotted out in Figures 11-13 for the E15 tests at 0, 150, and 300 hours of endurance, respectively. The difference in HC at the 300 hour emissions check was caused by the Mode 5 (idle) point as Figure 13 shows. The high variability of HC emissions at Mode 5 may have been caused by poor run quality leading to intermittent misfire as the equivalence ratio trended further lean of stoichiometric (<0.925) with increasing run time.







Figures 11, 12, and 13: Hydrocarbon Emissions Outputs for Each Emissions Test, E15 Engine on E15 Fuel

Engine Performance Comparison

The power and torque data from the E0 9.9HP engine is shown in Figure 14 below. [Note: All power and torque curves were normalized to a set torque and power to make consistent comparisons possible across different engines, fuels, and amount of endurance time. The highest power and torque values generated on any of the tests were used as the reference power and torque setting and the runs were normalized back to these values.] There was a clear trend of increasing power and torque with more endurance time on the E0 engine. There was an increase of 3.2% in peak power and a 2.1% increase in peak torque when comparing the zero hour test with the 300 hour test. Similar graphs for the E15 engine are shown in Figure 15 on the E0-EEE fuel and in Figure 16 on the E15 fuel. Figures 15 and 16 show that there was generally a trend of decreasing power and/or torque with more endurance time on the E15 engine. On the E0-EEE fuel there was no change in peak power, but a loss of 1% peak torque when comparing the zero hour test with the 300 hour test on the E15 engine. Results on E15 fuel were similar, with a loss of peak power of 0.9% and a loss of peak torque of 2.1% when comparing the zero hour test with the 300 hour test. The mechanism that caused the E0 engine to have increasing power vs. endurance time and the E15 engine to have decreasing power vs. endurance time is unclear.

Figure 17 shows a comparison of the fuel's effect on the engine performance. The E15 fuel power run shows more torque generation throughout the speed range tested. There is approximately 1.75% more torque (and therefore, more power) on average throughout the speed range. Due to the enleanment from the fuel change, the engine may have been operating in a range closer to the Lean Best Torque on the E15 fuel and/or the volumetric efficiency may have been improved due to the additional charge cooling afforded by the heat of vaporization difference of the fuels. Figure 18 shows the difference in exhaust gas temperatures during the same power runs on the 2 different fuels. There was an approximately 17°C increase in EGT on both cylinders due to the enleanment from the E15 fuel.

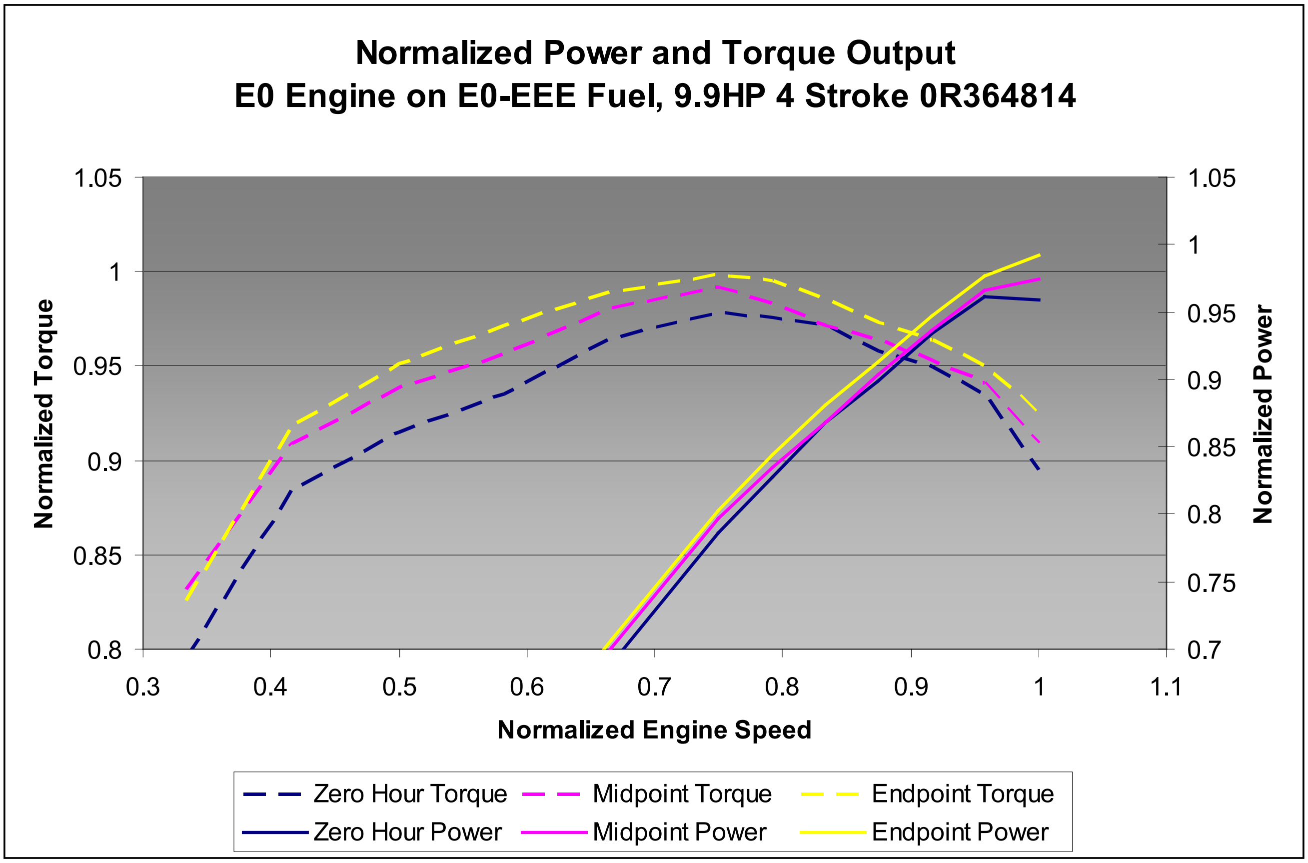


Figure 14: E0 Engine Power and Torque Output at Endurance Check Intervals

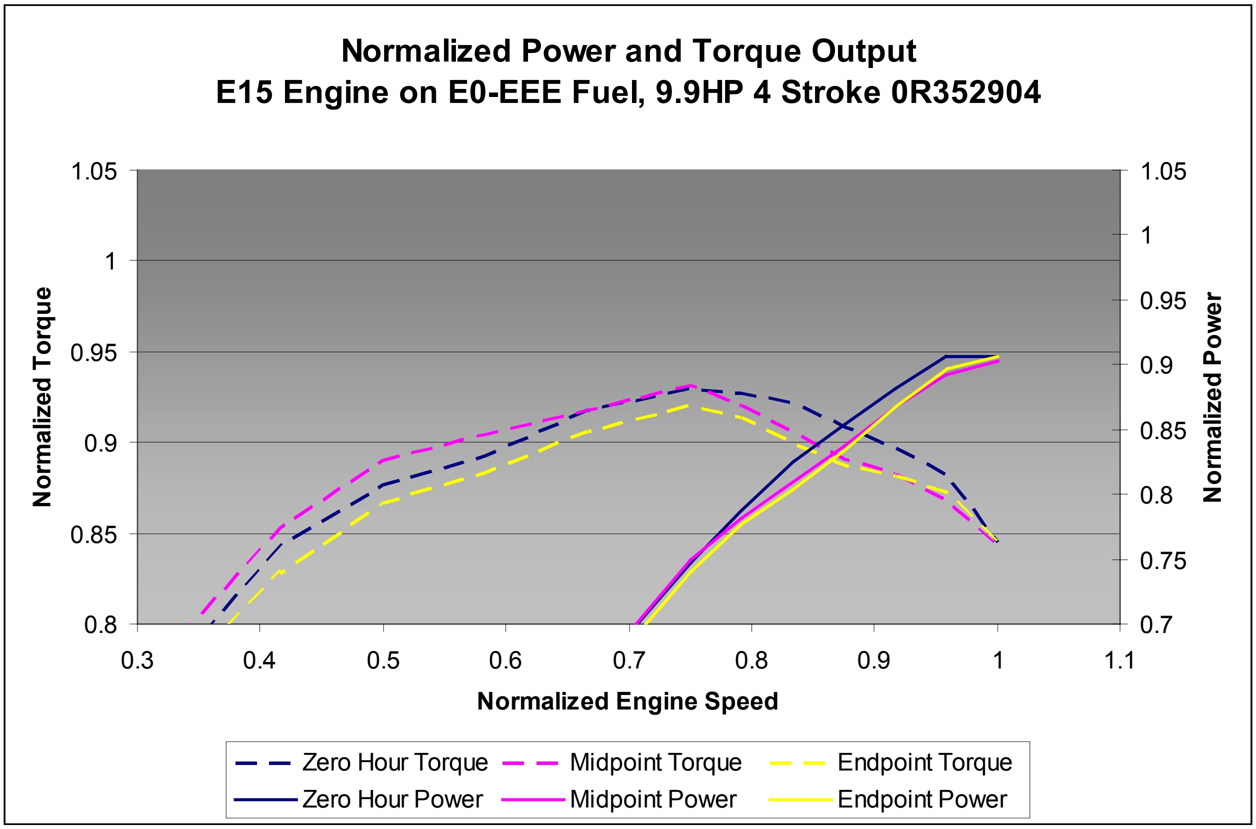


Figure 15: E15 Engine Power and Torque Output at Endurance Check Intervals-EEE-E0 Fuel

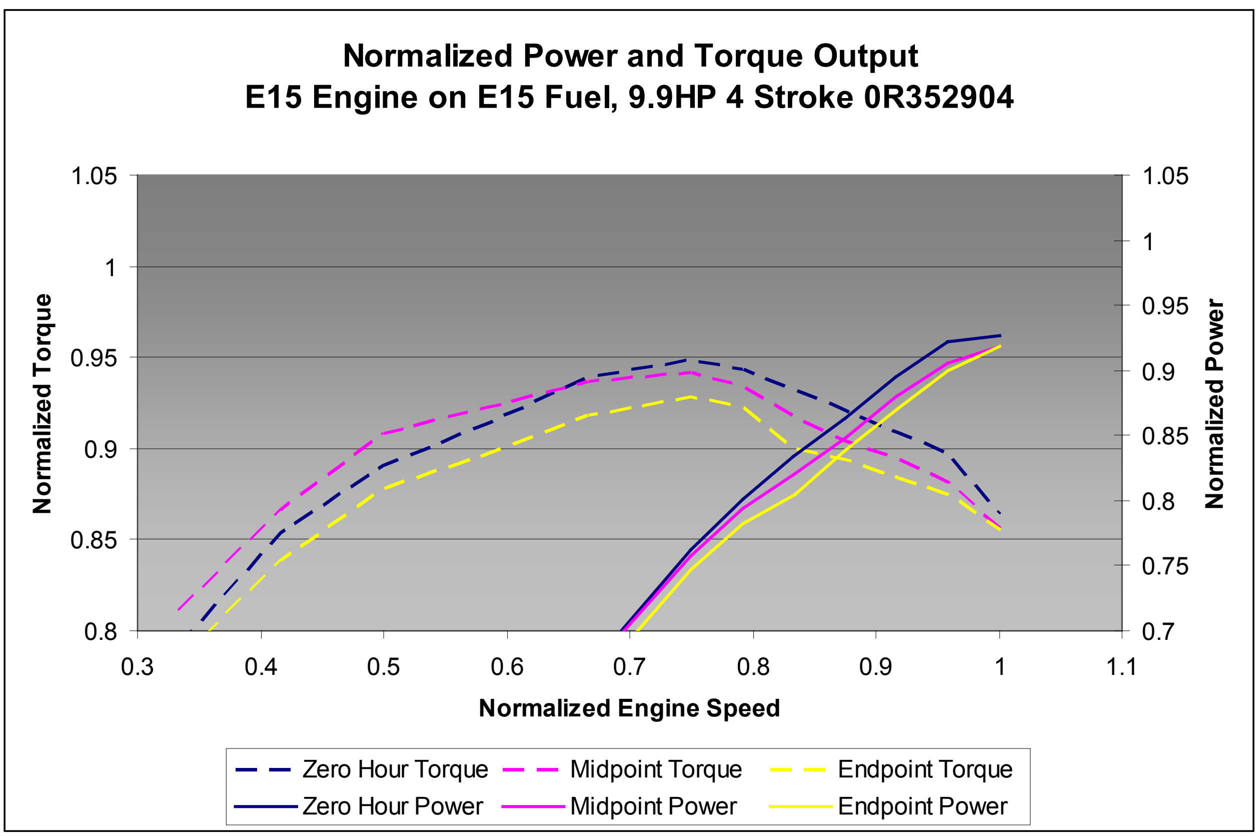


Figure 16: E15 Engine Power and Torque Output at Endurance Check Intervals-E15 Fuel

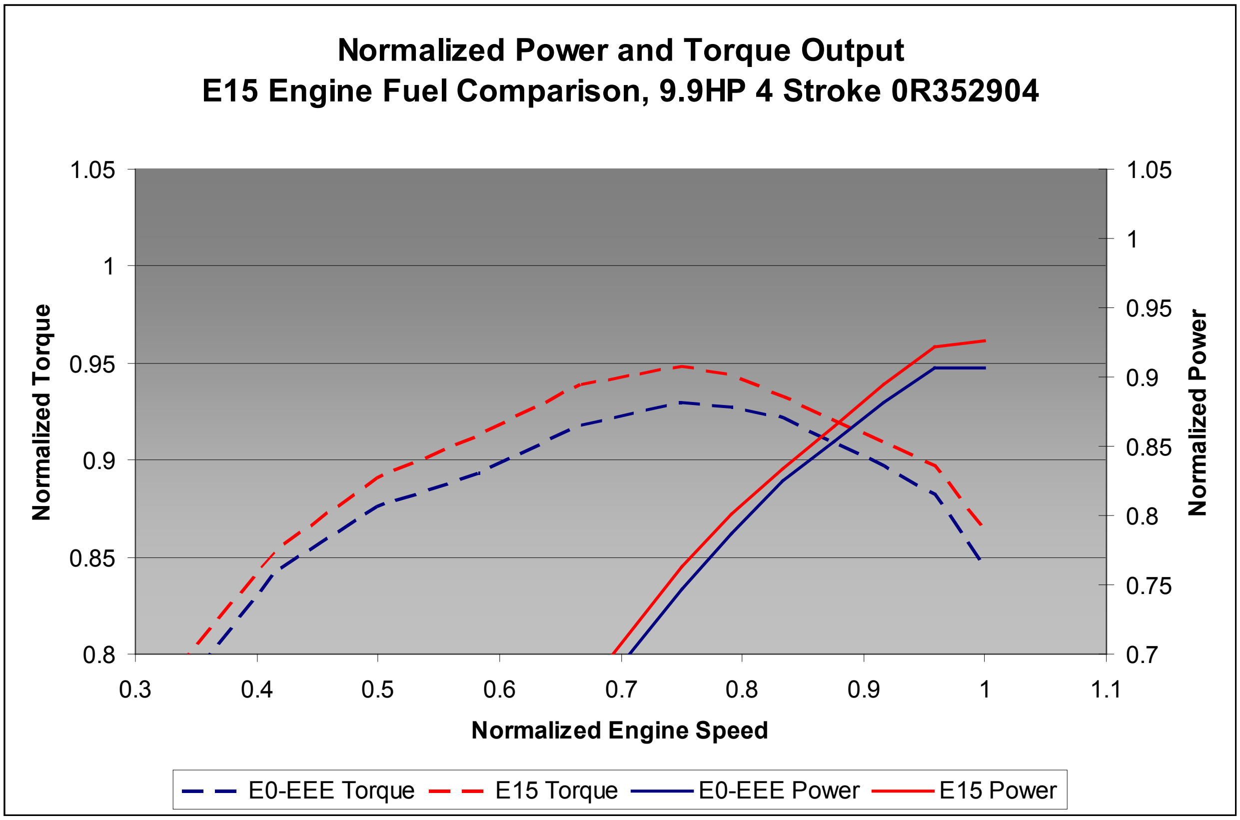


Figure 17: E15 Engine Power and Torque Output, Zero Hour Check-E0-EEE Fuel vs. E15 Fuel

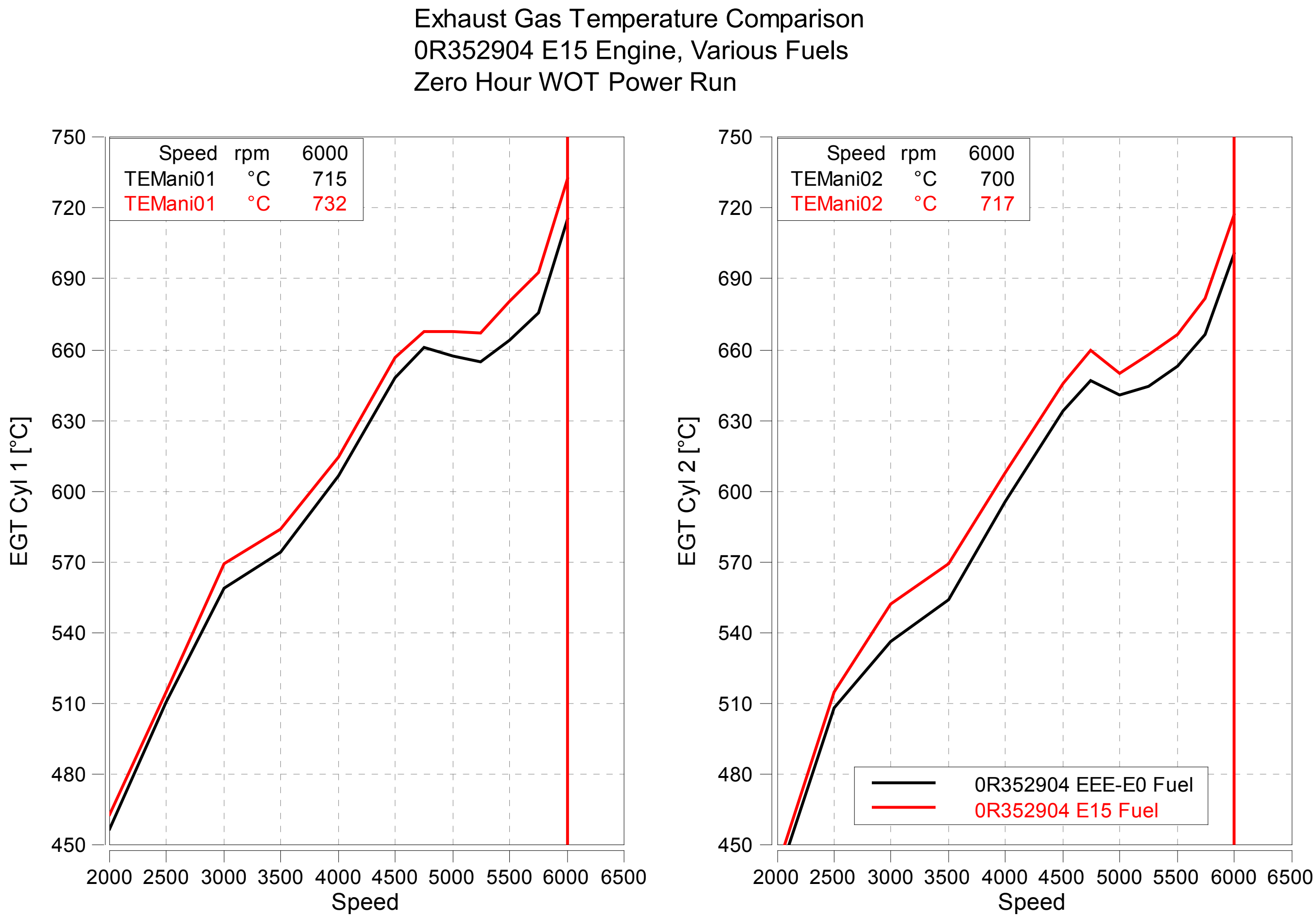


Figure 18: E15 Engine-Exhaust Gas Temperature Comparison, Zero Hour Check-E0-EEE Fuel vs. E15 Fuel

End of Test Teardown and Inspection

When the running engine testing was completed, the engines were disassembled and inspected. The main areas of focus were looking for signs of wear or deterioration and also material compatibility issues.

Upon initial inspection, there were indications that some of the main engine components on the E15 engine were subjected to higher operating temperatures. There were more carbon deposits observed on the undercrown area of the pistons and the small end of the connecting rod, suggesting that the pistons were operating at a higher temperature. Comparisons of the pistons and rods can be seen in Figures 19 and 20, respectively.

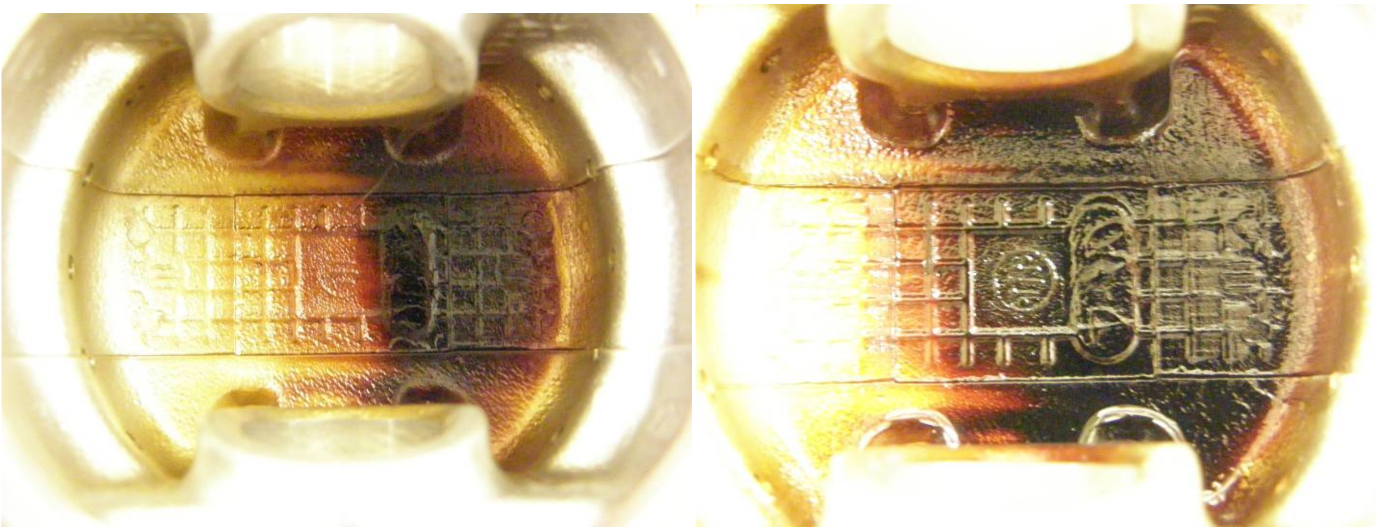


Figure 19: Piston Undercrown Carbon Deposit Comparison, Cylinder 1, E0 on Left, E15 on Right

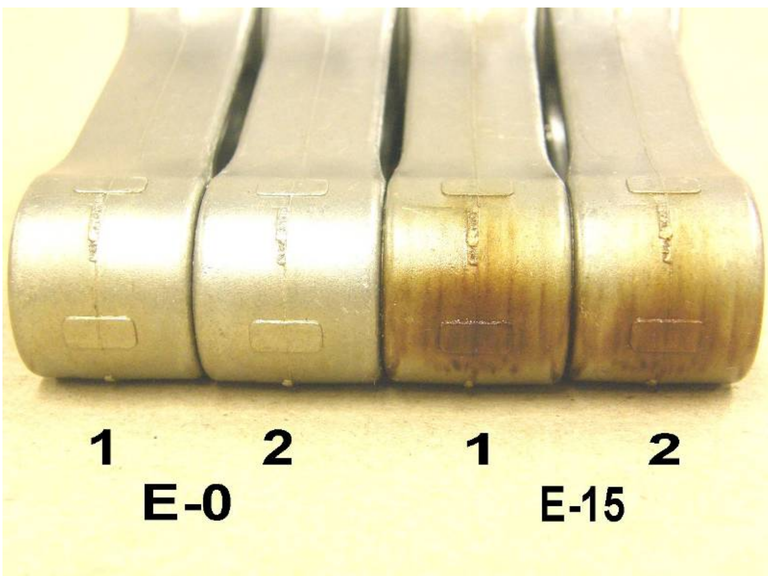


Figure 20: Small End of Connecting Rod Carbon Deposit Comparison, E0 on Left, E15 on Right

Although there were no indications of fuel pump failure during engine test, the mechanical fuel pumps were also disassembled and inspected following testing to look for abnormal signs of wear or degradation. The check valve gasket on the E15 engine showed signs of deterioration compared with that from the E0 engine. The gasket from the E15 pump had a pronounced ridge formed in the area that "hinged" when the check valve was in operation (see notes in Figure 21). The E15 gasket material in the area that sealed the check valve also had signs of wear that were more advanced than the E0 gasket. There was a significant amount material transfer from the gasket to the plastic check valve that it sealed as shown in Figure 22. Both fuel pumps were exposed to their respective test fuels for a period of approximately 2 months. More investigation is necessary to understand the effects of long term exposure of these components. It should be noted that the fuel pump flow performance was not tested. There were no indications that there was a problem with the fuel pump before disassembly. Once the deterioration was noted during teardown, it was determined that measuring the flow performance after disassembly and subsequent reassembly would have likely introduced error in the measurement.

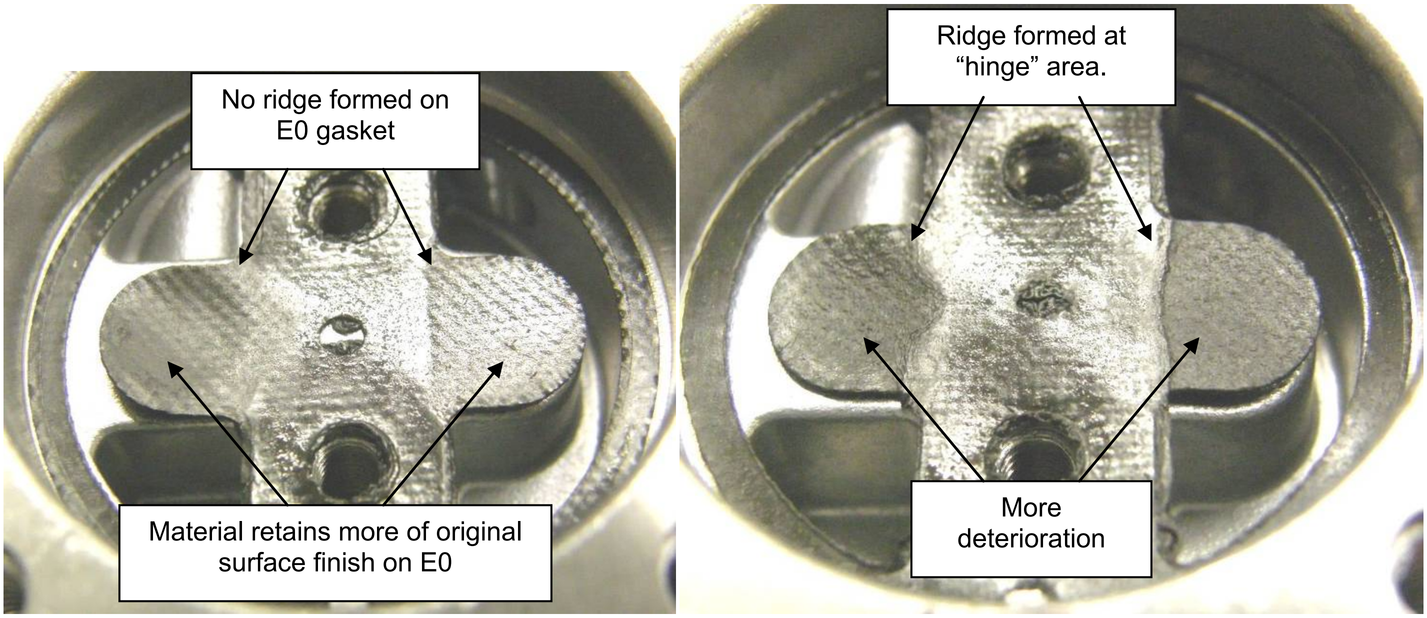


Figure 21: Fuel Pump Check Valve Gasket Comparison, E0 on Left, E15 on Right

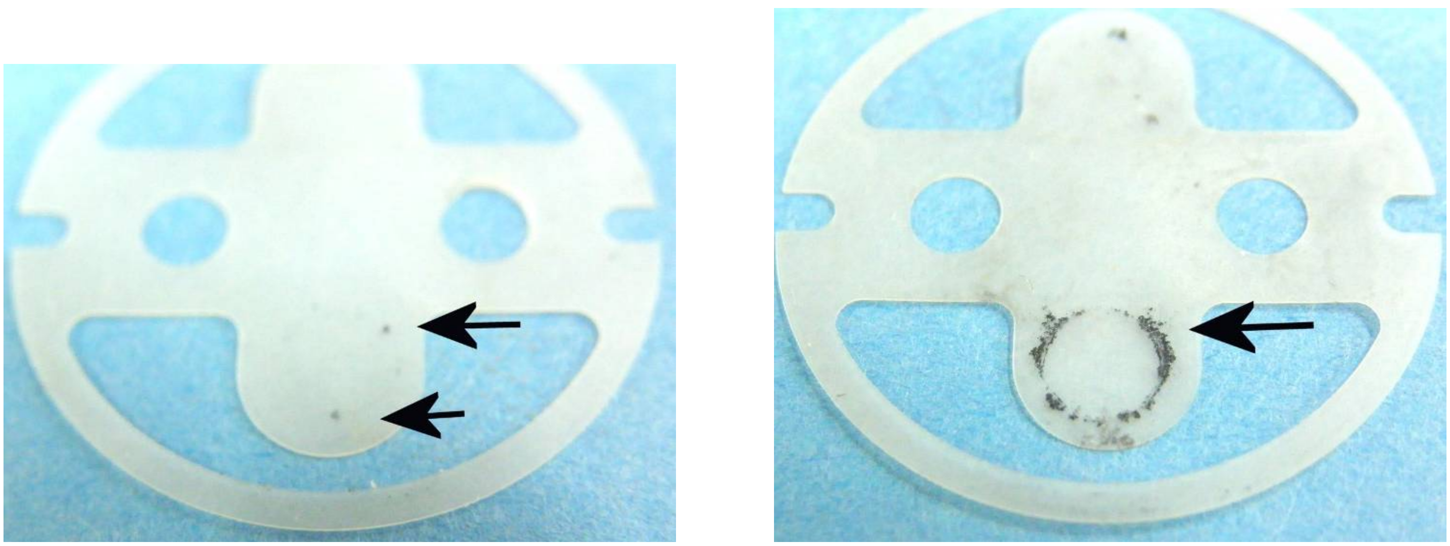


Figure 22: Fuel Pump Check Valve Comparison, E0 on Left, E15 on Right

Due to the visible differences in some of the engines’ metal components, several components were sent to the in-house metallurgy lab for further analysis. Results of this analysis are included in Table 3. The Vickers hardness test was performed using a Clemet Microharness Tester with a conversion to the Rockwell C scale where applicable (on steel parts). The Brinell scale was used for the aluminum parts, as they are much softer than the steel parts. The values shown were the average of 3 measurements for each component with the exception of the valve bridge in the cylinder head where only 2 measurements were taken. However, due to the fact that only 1 component from each engine on the 2 fuels was tested the results have no statistical significance and should be taken as an indicator only. Also, no hardness measurements were taken on the components prior to testing so there was likely some normal part-to-part variability in hardness as the components were originally manufactured.

Taking all of these issues into consideration there were indications that some of the components had different hardness values. These differences were most likely related to the continuous operating temperatures of the components. The most notable differences were the pistons, the valve bridge in the cylinder head and the intake valve stems. The piston measured from the E15 engine had a hardness value approximately 13.2% lower than the piston from the E0 engine. This would suggest that the E15 piston experienced a higher operating temperature, as expected due to the lean operation. The carbon deposits on the underside of the piston due to oil coking also suggest the E15 pistons were running hotter as noted previously. The intake valve stem measurements showed an approximately 12% difference in hardness, with the E0 engine having the lower values. This difference would suggest that the E0 intake valve stems were running hotter during operation than the E15. This difference was likely due to the charge-air cooling effect of ethanol in the E15 fuel resulting in cooling of the intake port and leading to lower intake valve stem temperatures. The evaporative cooling in the intake port could also explain why the valve bridge hardness measurements indicated that the valve bridge on the E15 engine had lower operating temperatures evidenced by the roughly 11% higher hardness value. The other measurements showed differences that were likely within the repeatability of the measurements and the manufacturing variability so no conclusions could be drawn from them.

The piston is generally a higher-stressed component than the intake valve. The reduction in hardness of the intake valve for the E0 engine is not likely to increase failure rates since this engine family was qualified for E0 operation as a baseline. However, if the reduction in hardness of the piston with E15 fuel was found to be a statistically significant result, E15 fuel usage might increase the failure rate of this component.

Table 3: Hardness Measurements on Various 9.9HP Four-Stroke Engine Components

9.9HP Four Stroke	Hardness Scale	**E0** 0R364814	**E15** 0R352904	Percent Difference
Piston, Cyl 1	BHN	91.0	79.0	13.2%
Connecting Rod, Small End Cyl 1	BHN	112.0	112.0	0.0%
Exhaust Valve Stem, Cyl 1	Rc	21.7	22.1	-2.0%
Exhaust Valve Head, Cyl 1	Rc	30.1	30.7	-2.0%
Valve Bridge in Cyl. Head, Cyl 1	BHN	83.0	92.0	-10.8%
Intake Valve Stem, Cyl 1	Rc	33.0	36.9	-11.9%
Intake Valve Head, Cyl 1	Rc	39.6	39.1	1.3%

Verado 300HP Supercharged Four-Stroke:

Endurance Test Results

Several engine failures occurred during endurance testing on the Verado engines, two of which were not related to the fuel and one of which may have been associated with the use of E15 fuel. The two non-fuel-related engine failures included a casting defect and a test facility induced failure. A third engine failure, involving failed exhaust valves is believed to have been caused by the E15 fuel. Failure mechanisms are described in detail below.

<u>E0 Engine #1-Casting Defect</u>: The first engine to fail was the E0 Verado-serial number 1B812775. At 177 hours of WOT endurance (204.2 total engine hours) the engine was shut down for a routine oil check. An excessive amount of water was found in the oil. The engine was disassembled and the major components were pressure checked. A leak path was discovered from the water jacket to the intake port on one cylinder. The cylinder head was sectioned and an oxide fold line from the casting process was discovered. This defect was present from the time of the original casting process and took thermal cycling, load, and time to cause a leak. It was in no way associated with the fuel.

<u>E0 Engine #2-Test Facility-Induced Failure:</u> An additional engine was obtained to replace the original E0 engine and this engine was given the serial number 1B821775A. This engine did the initial dyno tests and was put on endurance. After 88.7 hours of WOT endurance (98 total engine hours), the engine was automatically shut down by the endurance facility control system for low exhaust gas temperature. Investigation showed water entering the exhaust stream. The engine was then disassembled and a significant amount of mineral deposits were found in the cooling passages, especially in the exhaust collector on the cylinder head. See Figure 23. [Note: For a coolant fluid, outboard engines draw in water from the body of water they are operating in, which in this case was the endurance test tank.] An interaction between

the pH and hardness of the water in the test tank created conditions that precipitated out minerals (primarily calcite) when exposed to the elevated temperatures in the cooling passage, especially near the exhaust collector. The blocked passages prevented adequate cooling in the exhaust collector, which eventually failed the head gasket and allowed water to enter into the exhaust stream. See Figure 24. It should be noted that these water chemistry conditions were specifically caused by the test facility water conditioning and would not be something that the engine would experience in real-world use.

Figure 23: Mineral Deposits in Cooling Jacket, E0 Verado 1B812775A

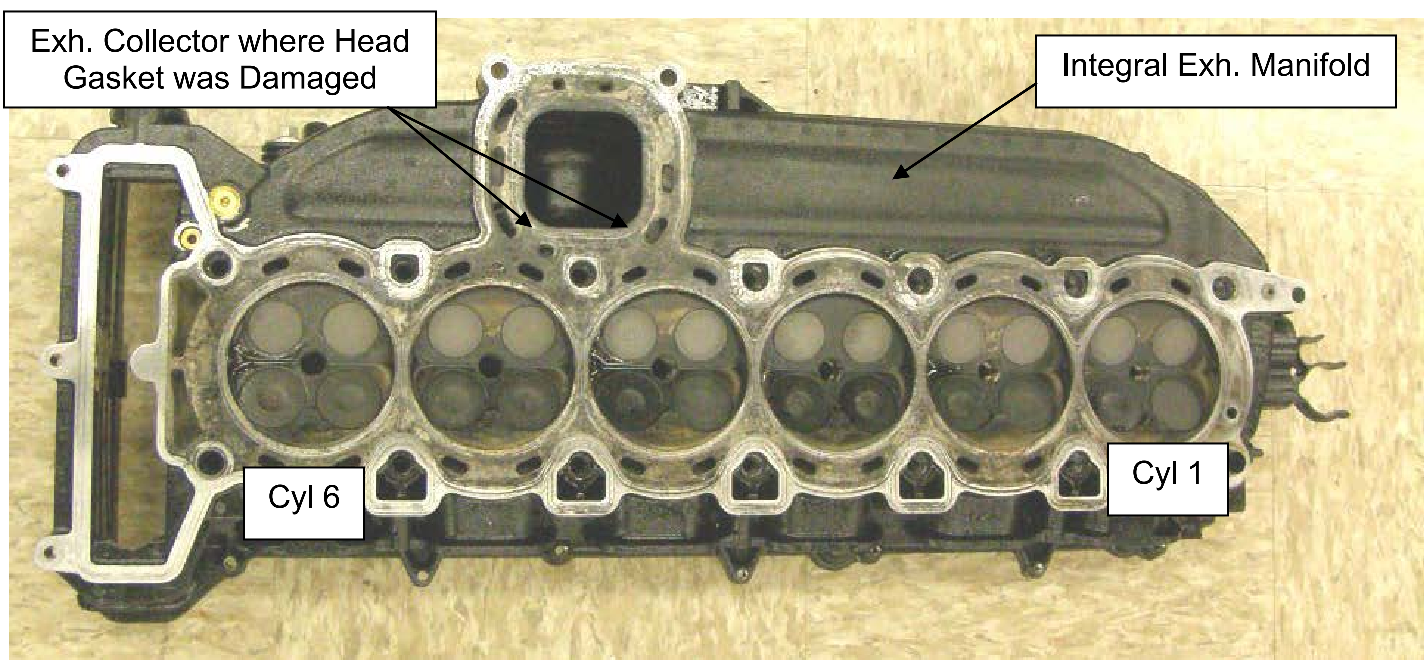


Figure 24: Verado Cylinder Head Indicating Where Head Gasket Failure Occurred, E0 Verado 1B812775A

E15 Engine: At 285 hours of endurance operation (323 total engine hours), the E15 Verado test engine (serial number 1B812776) was noted to have rough idle after restarting shortly after maintenance was performed. A compression check was performed showing no compression on cylinder 3. During disassembly a broken exhaust valve was found in cylinder #3. Further investigation found that the other exhaust valve on cylinder 3 had developed a crack, as well as one of the exhaust valves in cylinder 6. See Figures 25 and 26. NOTE: The images shown in Figure 26 of the cracked exhaust valves had been cleaned of deposits prior to photography.

Figure 25: Broken Exhaust Valve from E15 Verado 1B812776, Top Valve in Cylinder 3

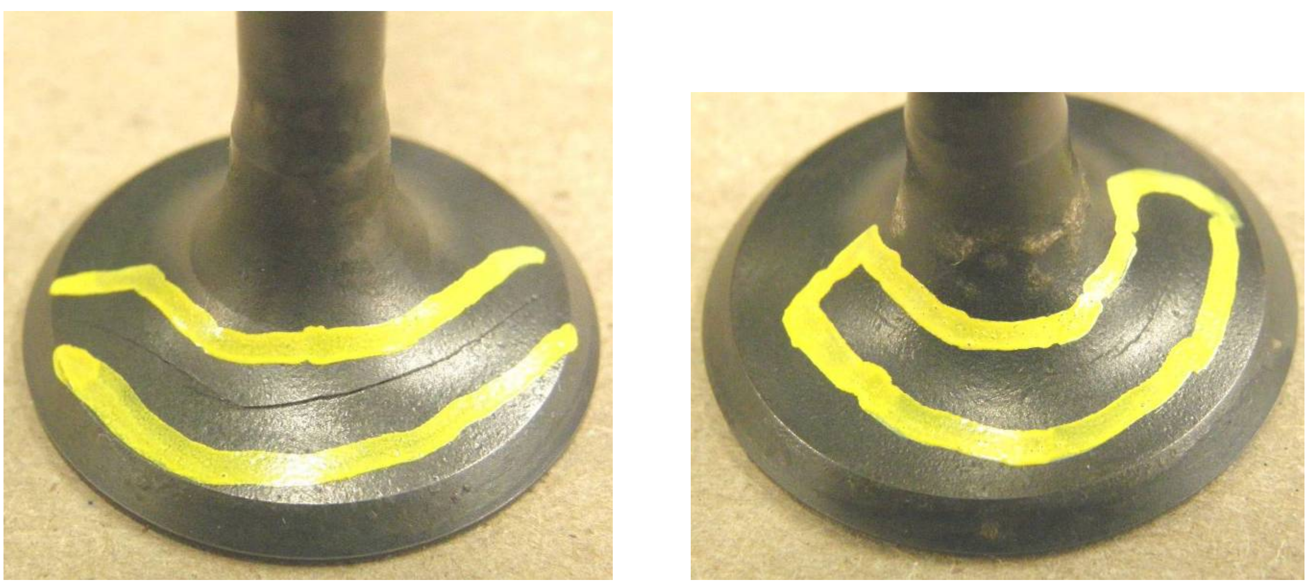


Figure 26: Cracked Valves from E15 Verado 1B812776, Bottom Valve in Cyl. 3 Left, and Top Valve in Cyl. 6 Right

The cracked valves and several valves without cracks from the E15 Verado were analyzed in Mercury's materials laboratory. The cracked valves were visually inspected with an optical stereoscope. The fatigue initiation sites were clearly identified. Figure 27 shows an example of the images of the initiation sites from the bottom exhaust valve from cylinder 3.

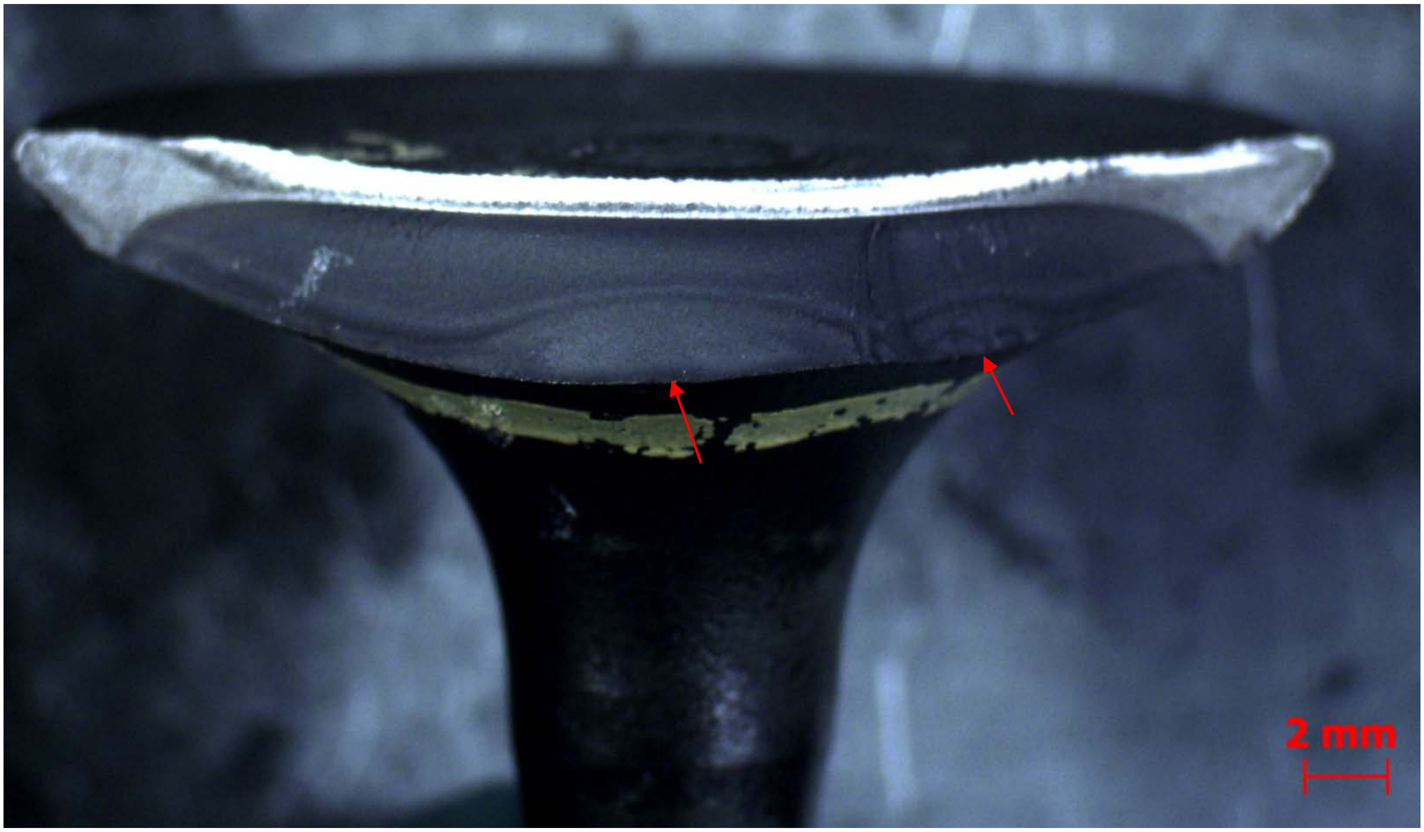


Figure 27: Fatigue Initiation Sites on Cylinder 3 Bottom Exhaust Valve, E15 Verado 1B812776

In addition to finding the fatigue initiation sites, the failed valves were checked for hardness. The cracked valves from the E15 engine were found to have hardness values much lower than new valves and below the minimum print specification of a new valve. Other sample valves were collected and analyzed from WOT endurance Verado engines that were run on E0 pump fuel during the same general timeframe as the E15 engine was run. In addition, samples of new valves were also acquired and analyzed. The hardness measurements showed that the valves from the engines operated on E0 fuel were actually harder than the new valves. The summary of hardness measurements are shown in Table 4. Note: All of the measurements were taken in the Rockwell A scale and converted to the Rockwell C scale due to the fact that the samples were mounted and polished to perform hardness measurements in the center of the cross section. This would negate any hardness effects from the mounting material.

Table 4: Verado Exhaust Valve Hardness Measurement Summary

Valve Description	Hardness (HRC)
E15: 1B812776 Cyl 3 Bottom	22
E15: 1B812776 Cyl 6 Top	22
E0: 1B812775 Cyl 3 Bottom	37.5
E0: 1B812775 Cyl 3 Top	36.5
E0: 1B812775A Cyl 3 Top	38
E0: 1B828629 Cyl 2 Top	37.5
New Valve #1	34.5
New Valve #2	34.5
New Valve #3	33
New Valve #4	33
New Valve #5	33.5

The Verado exhaust valves are made from Inconel 751, which is a heat-treatable alloy. This trait was used to estimate the metal temperatures experienced by the valves. The valve hardness data in Table 4 collected from the E0 engines suggested that the metal temperatures experienced during operation were in a range that allowed age-hardening of the metal to make the valves increase in hardness. The hardness values of the E15 engine valves suggested that they were operating in a temperature regime that significantly reduced the hardness. In order to understand the hardness versus temperature, the new valves that were hardness checked were heated in an oven for 24 hours at various temperatures and then hardness was checked again. Figure 28 shows the results from the oven heating operation on the new valves. In Figure 28, the blue line shows the hardness data of the new valves before heat treatment and the red line shows the hardness data of the valves after heating. At metal temperatures above 870°C, the valves showed a dramatic decline in hardness according to this test data. The data suggest that the exhaust valves from the E15 engine may have experienced temperatures nearing 900°C.

One possible mechanism by which the E15 exhaust valves may have experienced such high temperatures would be a disruption of valve cooling during the portion of the cycle where the valve should be fully seated. During inspection, it was noted that several cam lobes showed wear and marking on the base circle portion of the lobe indicating that the exhaust valves had run out of lash. This suggested that excessive wear or valve head deformation may have occurred during operation, which caused the lash to diminish. This would have prevented the valve from seating properly resulting in a significant valve temperature increase due to lack of cooling on the seat. The valves or seats may have also had accelerated wear to diminish the lash due to lack of lubricity of the E15 fuel or because of the elevated temperatures caused by the lean operation on E15 fuel. In addition, if the exhaust valves were experiencing higher operating temperatures due to the higher exhaust gas temperatures from using E15 fuel, the overall length of the valve would be slightly longer. This longer length during operation would also reduce the amount of lash in the valvetrain and make the engine more prone to base circle contact on the cam. Plots comparing the measured cold valve lash over the course of endurance between the E0 and E15 engines are shown in Figures 32 and 33 below.

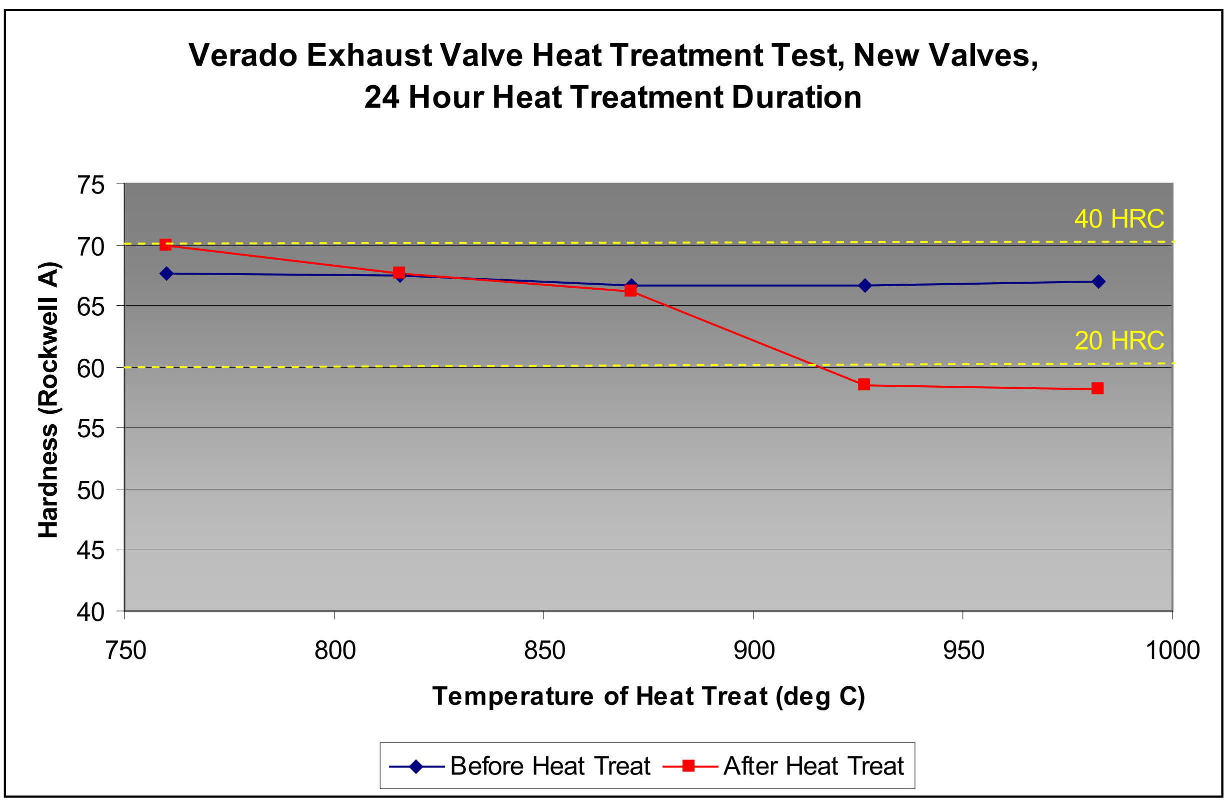


Figure 28: Heat Treatment Test of New Verado Valves

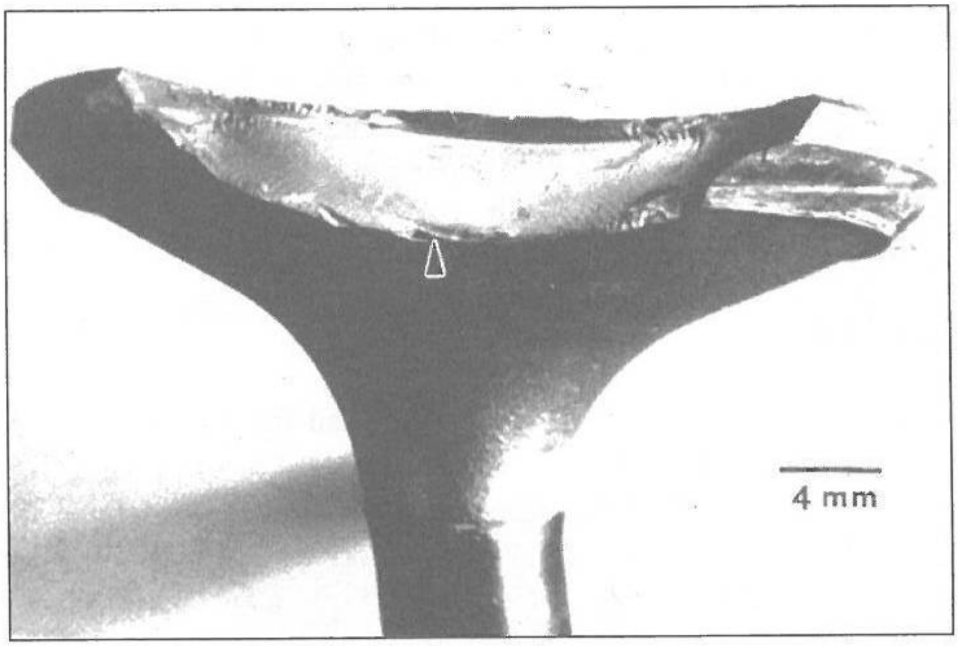


***Figure 6.8** Example of valve fillet fractures due to overstress, at elevated temperatures, and a corrosive environment; the arrow shows the crack initiation site at the fillet (Wang* et al.*).*

Figure 29: Exhaust Valve Failure from Literature Research Showed Similar Failure Mechanism [8]

Similar failure mechanisms were found in a literature search as shown in Figure 29. The failure is noted as a classic over-temperature failure. *"High temperatures and a corrosive environment at the exhaust fillet substantially weaken the valve strength."*[8] from: Introduction to Engine Valvetrains by Yushu Wang

Extensive development went into the valvetrain on this high-output engine. Upgrading the engine to account for higher exhaust gas temperatures due to a wider range of fuel properties would not be easily accomplished. The current production Verado exhaust valve is Inconel 751, which is categorized in the "superalloy" material classification.

It should be noted that the E15 engine (1B812776) was operating for a period of time when the mineral precipitation problem occurred on the second E0 engine (1B812775A). However, it is not believed that this contributed to the valve failure. The E15 engine (1B812776) did have some accumulation of precipitation flakes in the exhaust collector area, but not nearly to the extent that the E0 engine did. The E15 engine (1B812776) was not operating the entire time the E0 engine (1B812775A) ran when the mineral precipitation problem occurred. The head was sectioned and there were no mineral precipitation deposits on cooling jacket surfaces in cylinder 3 where the worst valve failure occurred. See Figure 30 for a picture of the sectioned head from the E15 engine (1B812776) showing no mineral deposits were present. Yellow spots in the cooling jacket were anti-corrosion coating from production where the paint did not fully coat interior surfaces of the cooling jacket. Figure 31 shows the same section of cylinder head from the E0 engine (1B812775A) that failed due to the mineral precipitation. This E0 engine (1B812775A) was also inspected for cracked exhaust valves and none were found. In addition, the hardness values of the exhaust valves were measured (see Table 4) indicating that the mineral precipitation issue did not affect the valve hardness on the E0 engine (1B812775A). There were several other Verado engines that were running endurance testing for a different project that failed due to the mineral precipitation issue. All other Verado engines that failed due to the mineral precipitation failed the head gasket in the exhaust collector area.

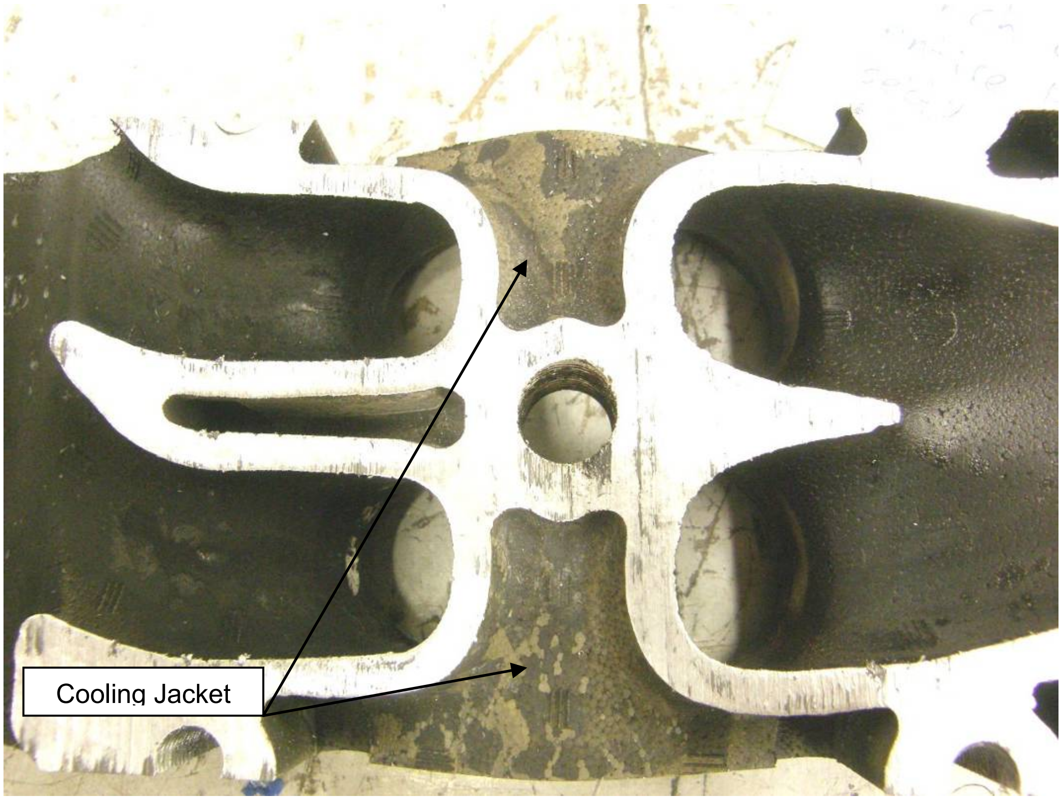


Figure 30: Photo of Section of Cylinder 3, E15 Verado 1B812776, Exhaust Ports on Left

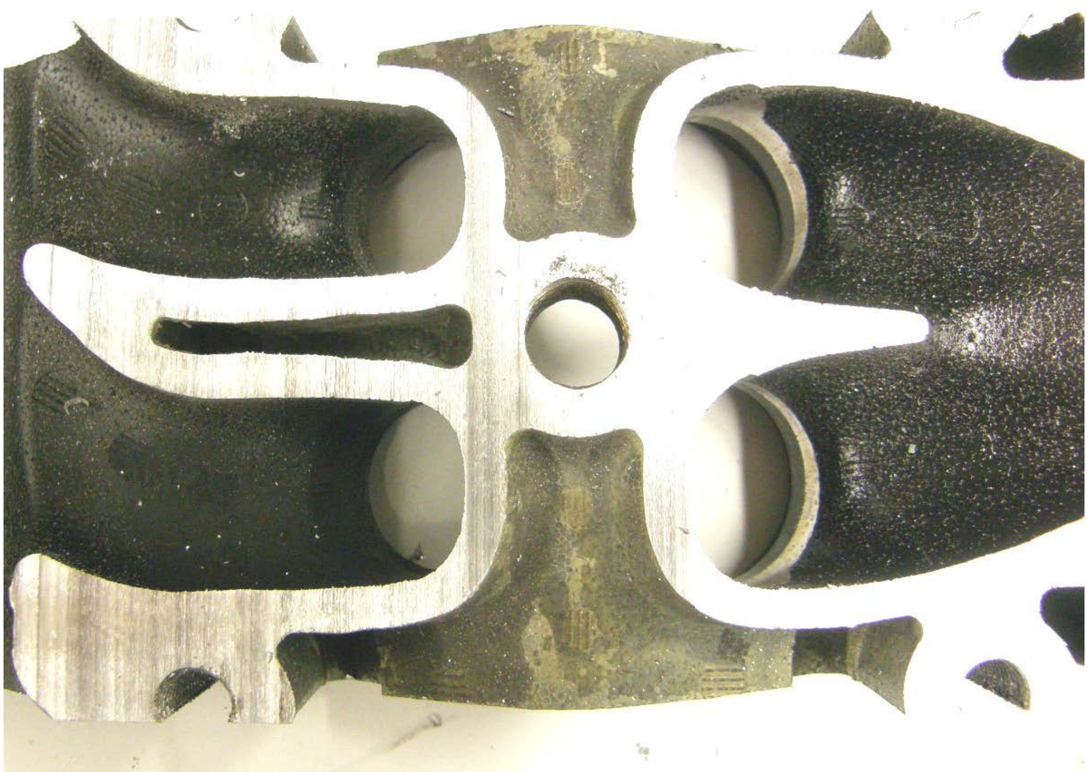


Figure 31: Photo of Section of Cylinder 3, E0 Verado 1B812775A, Exhaust Ports on Left

E0 Substitute Engine: In lieu of a completed test on E0 fuel, a substitute engine was chosen that had already been through endurance testing (serial number 1B828592). The engine that was used as a substitute had completed 372 hours of WOT endurance testing and was still intact. It ran in the same test facility running under the same test procedure as all other endurance testing as part of this project. The engine was used for a gearcase durability test for a different project so the rest of the engine was completely stock and built on the production line as were the other engines in this project. As such, it provided a suitable replacement for the incomplete E0 tests. For reference, the replacement engine (1B828592) was on test between the following dates: 11/15/2010 through 12/14/2010. The E15 engine 1B812776 was on test between 9/21/2010 through 11/12/2010.

As part of routine maintenance and checks during endurance, several valve lash measurements were taken at various intervals on the E0 substitute engine. Figures 32 and 33 below show the lash measurements during the course of endurance for both the E0 substitute engine (1B828592) and the E15 engine (1B812776), respectively. The solid red lines in the graph indicate the upper and lower lash specification on a new engine. It is clear from the lash measurements on the 2 engines that the E15 engine had a significantly faster decline in lash than the E0 substitute engine. The E0 substitute engine had 1 valve with higher lash value at the end of testing. There may have been some carbon or other deposits holding this valve off the seat during the measurement.

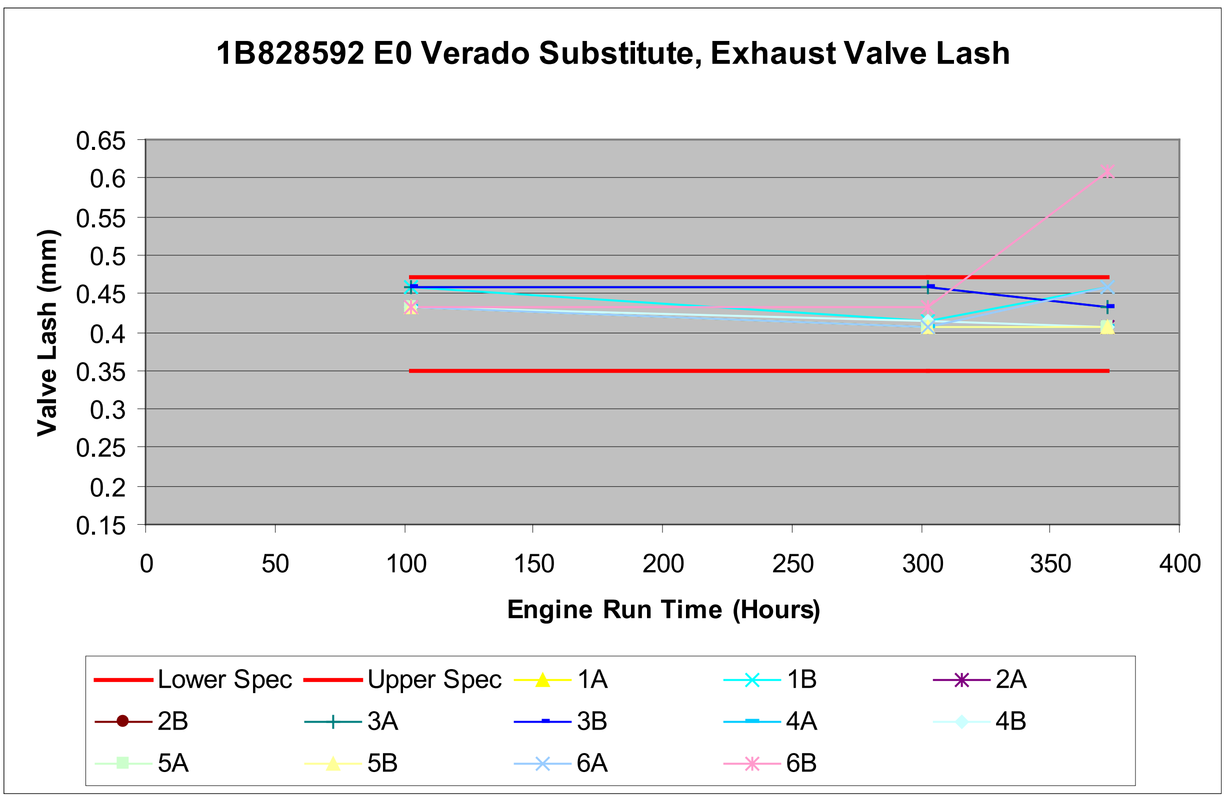


Figure 32: Exhaust Valve Lash (Measured Cold) vs. Endurance Time, E0 Substitute Engine

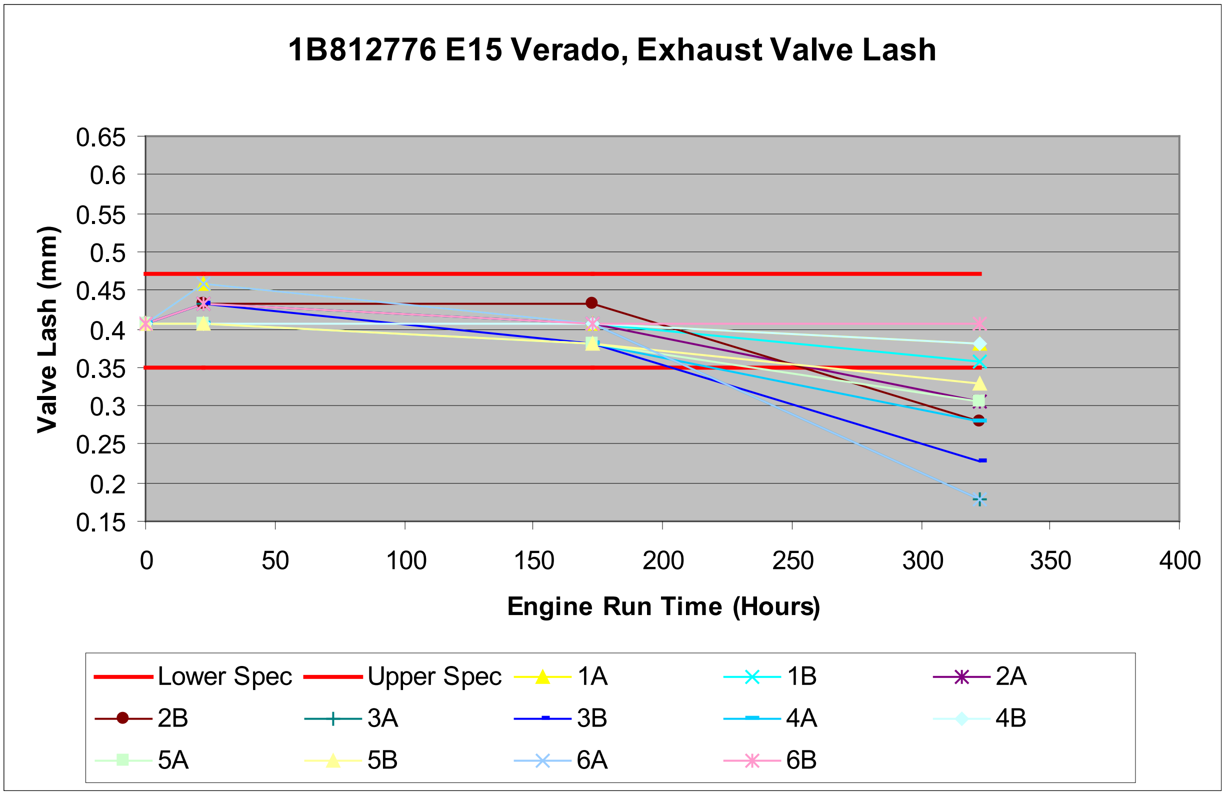


Figure 33: Exhaust Valve Lash (Measured Cold) vs. Endurance Time, E15 Engine

Emissions Testing Results

Due to failures of both the E0 and E15 engines, a complete analysis of the deteriorated emissions was not possible. However, with the data available several conclusions could be made. Figure 34 shows a graph of the Verado emissions that were collected. As was the case for the 9.9HP emissions data plots, each data point on the curve represents the average emissions value of the 3 emissions tests performed at each interval with error bars showing the range of the 3 emissions tests. The dashed yellow line shows the data from the original E0 engine (serial number 1B812775). The solid red and blue lines show the emissions data from the E15 engine (serial number 1B812776) using E15 and E0 (EEE) fuels, respectively. The single point in light blue at 372 hours shows the end of test emissions results for the substitute E0 engine (EEE fuel, serial number 1B828592). The graph shows a generally declining HC+NOx trend for the 2 original engines which is typical of Verado engines. The declining emissions trends on both engines would suggest that the ethanol fuel blend did not adversely affect the emissions deterioration on the Verado engine. The most notable aspect of the emissions output on the E15 engine was the fact that the total HC+NOx on E15 fuel was above 25 g/kw-hr, whereas the value on EEE-E0 was 21.5 g/kw-hr. The Family Emissions Limit (FEL) was set to 22 g/kw-hr for this engine family. A Verado engine generating 25 g/kw-hr would have failed an emissions audit. The increase in emissions can be primarily attributed to a significant increase in NOx due to the lean operation. Since the Verado is a highly boosted engine it is very sensitive to NOx generation due to changes in equivalence ratio. However, there was also an increase in HC emissions due to the E15 fuel, which would not be expected with a leaner equivalence ratio.

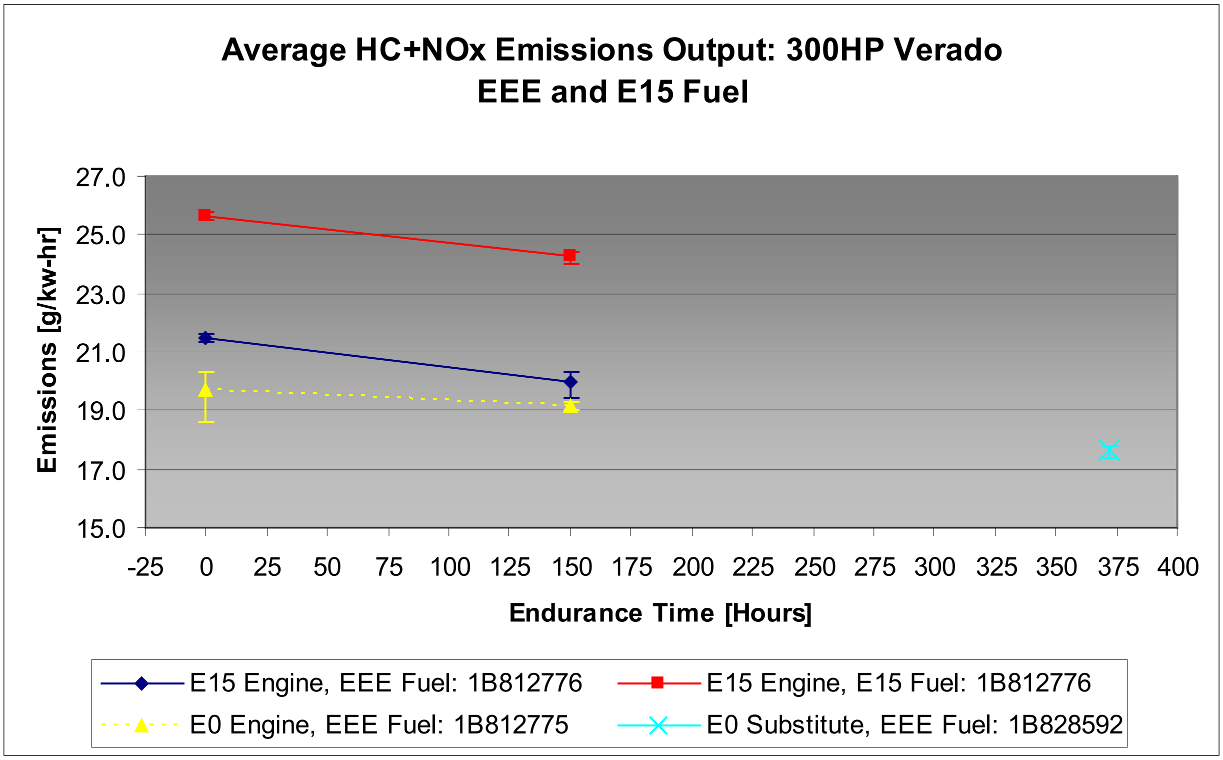


Figure 34: 300HP Verado HC+NOx Emissions Results Summary

In order to better understand the differences in the emissions outputs between the 2 fuels, graphs were made for each constituent of interest. Figures 35 through 37 show the NOx, HC, and CO emissions differences. The graphs were broken down by mode point for emissions tests performed prior to endurance on the E15 engine (1B812776). The values shown are the averages of the three repeated runs at "zero" hours.

Figure 35 shows the NOx emissions trends for the 2 fuels. The main differences were at Modes 1 and 2 which were both high load, boosted operating points. The fact that the NOx increased significantly with a lean shift due to the ethanol fuel blend was not surprising. Modes 3 and 4 did not show much difference because the engine was calibrated near an equivalence ratio of 1 on E0 fuel. The NOx trend with respect to equivalence ratio was near the peak at these points so a lean shift did not result in a significant change in NOx. Mode 5 was idle so the NOx generation at that point was essentially zero.

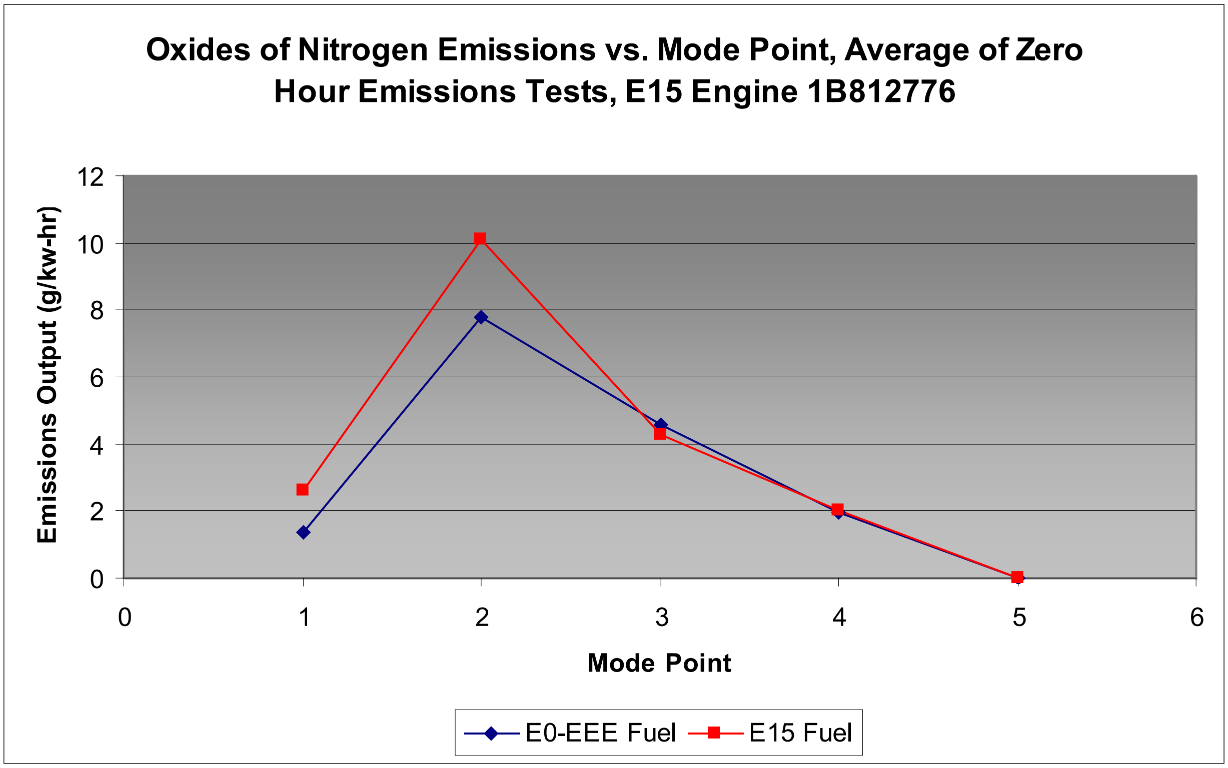


Figure 35: 300HP Verado NOx Emissions Results by Mode Point, Representative Zero Hour Test Data

The increase in HC output on E15 fuel was not an expected outcome of the test. Figure 36 highlights the difference in HC emissions between the 2 fuels. The main difference occurred at Mode 3, so further investigation was necessary into Mode 3 data specifically. However, it was also apparent that the HC output on E15 fuel was higher at Modes 1-4 despite the leaner operation from the fuel chemistry. This may suggest that the vaporization of the E15 fuel was inferior to that of the EEE fuel leading to poor fuel preparation. This is supported by data from Modes 1 and 2 where NOx and CO trends show that the engine did run leaner, yet had higher HC output when operated with E15.

The HC difference at Mode 3 was likely a result of the engine running substantially leaner than lean best torque (LBT). In this operating region, the Verado engine is calibrated slightly lean of the stoichiometric mixture on E0 fuel. With the use of E15 fuel, the engine operates significantly lean of LBT and, therefore, the torque production diminishes significantly. As a result, to achieve the specified torque set point for Mode 3 the throttle input had to be increased, yielding higher airflow and higher fuel flow. The fuel flow increased nearly 10% for essentially the same torque production with E15 fuel. In addition, it was noted that the intake air temperature was 12°C cooler at Mode 3 with E15 fuel. The cooler charge temperature was likely a result of the increased fuel vaporization cooling effect from the ethanol. The cooler temperatures in the intake may have impaired fuel preparation. The higher fuel flow combined with the inferior fuel preparation was likely the cause of the high HC output at Mode 3.

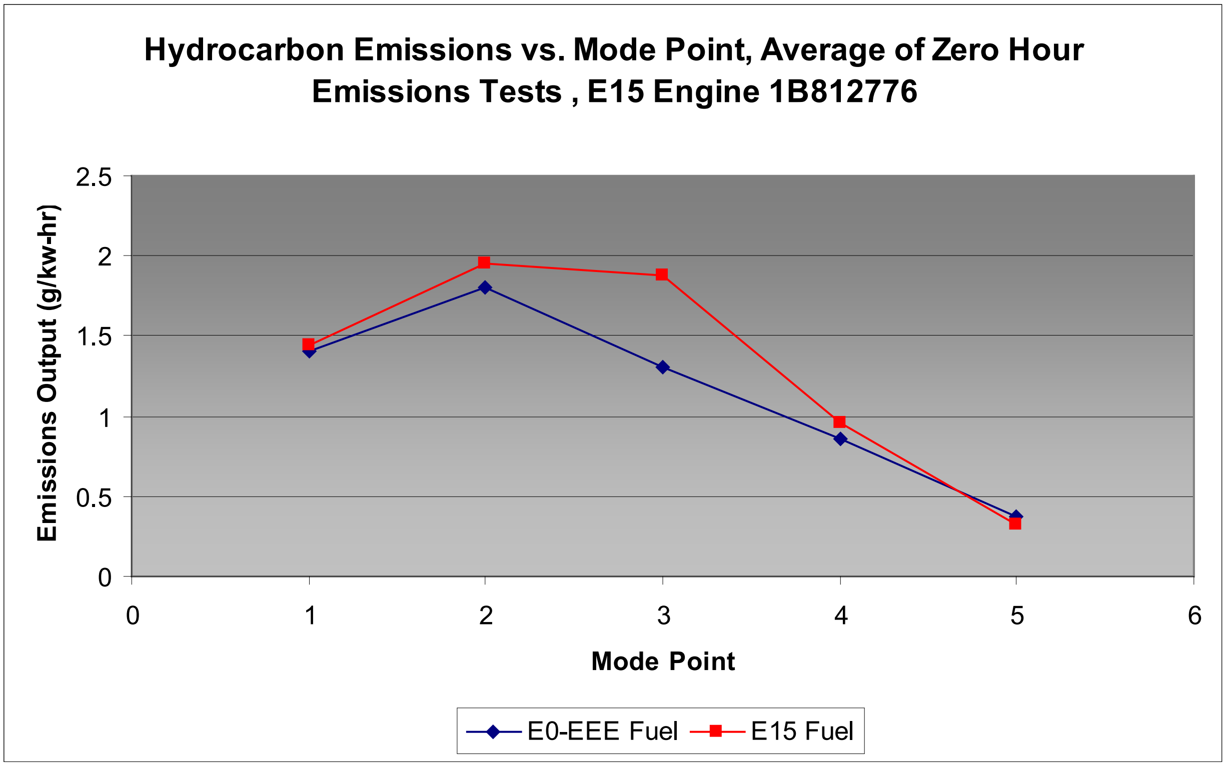


Figure 36: 300HP Verado HC Emissions Results by Mode Point, Representative Zero Hour Test Data

The CO emissions vs. emissions test mode point are shown in Figure 37. There was a significant reduction in CO emissions at Modes 1 and 2 when the engine was operated on E15 fuel, as expected. Modes 1 and 2 are calibrated rich of a stoichiometric mixture on E0, so the enleanment from E15 caused a reduction in CO. Modes 3-5 are generally insensitive in regard to CO because the operating points are calibrated near the stoichiometric mixture, so leaning the engine out due to the fuel had little effect at reducing CO relative to the changes seen at Modes 1 and 2.

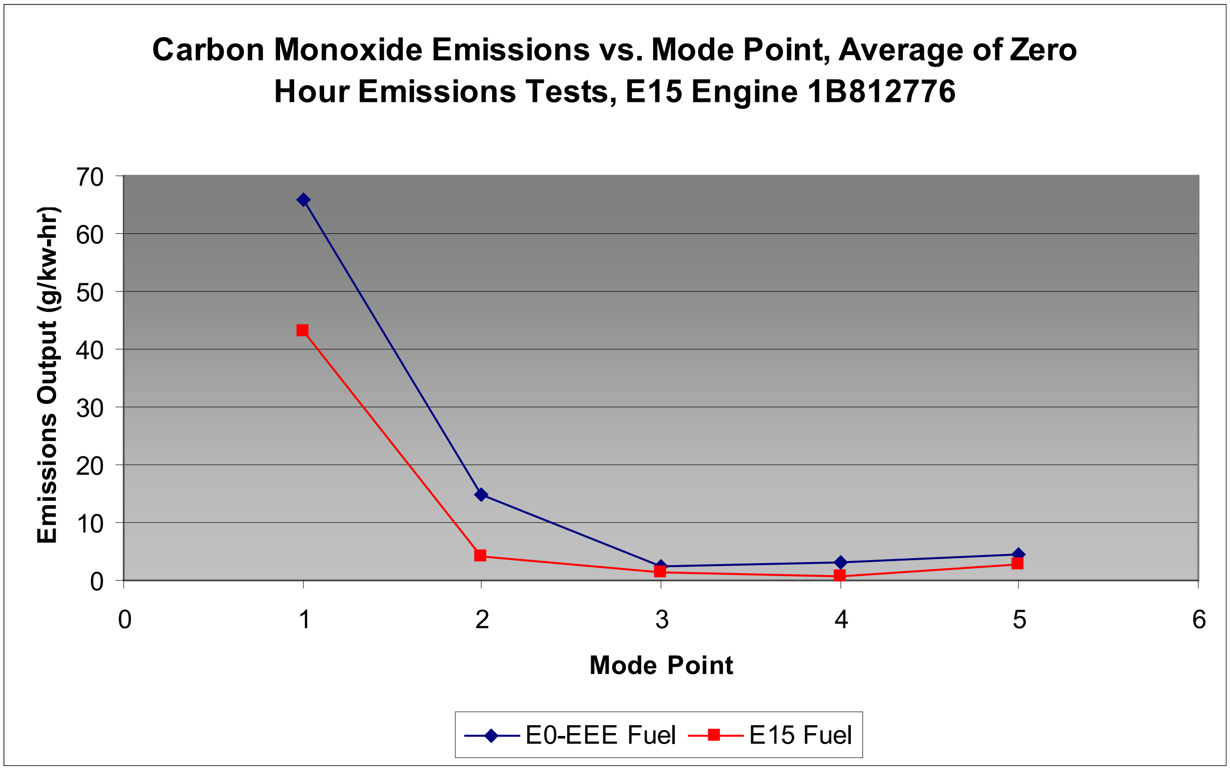


Figure 37: 300HP Verado CO Emissions Results by Mode Point, Representative Zero Hour Test Data

Engine Performance Comparison

Due to the engine failures, a complete comparison of engine performance vs. run time was not possible. The normalized power and torque data from the E0 Verado is shown in Figure 38. The changes from zero hours to 150 hours were less than 1% for peak torque (negligible) and a 2.3% reduction in peak power. The E0 engine produced less power output than the E15 engine when operated on the same E0 fuel. This difference of approximately 2% is considered normal production engine-to-engine variability.

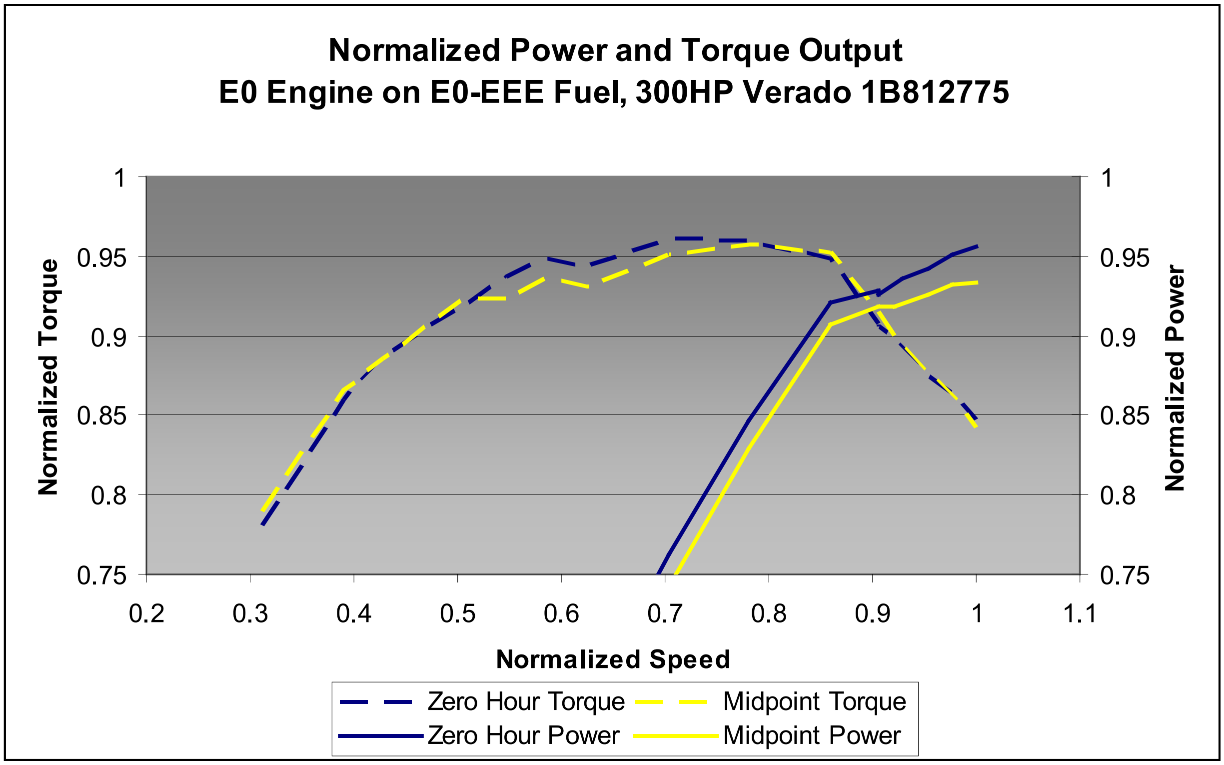


Figure 38: E0 Engine Power and Torque Output at Endurance Check Intervals-EEE-E0 Fuel

Power and torque data (normalized) for the E15 engine on both EEE-E0 fuel and E15 fuel is shown in Figure 39. There was an improvement in peak torque of 3.0% and in peak power of 1.5% when comparing the zero hour and midpoint runs on E0-EEE. The E15 engine showed negligible differences when comparing the midpoint power runs on E0-EEE and E15. It is unclear why this engine seemed unresponsive to the differences in charge cooling afforded by the ethanol blend fuel. Note: There was not a power run completed on E15 fuel at the initial zero hour measurement, which is why the midpoint data is compared in these figures.

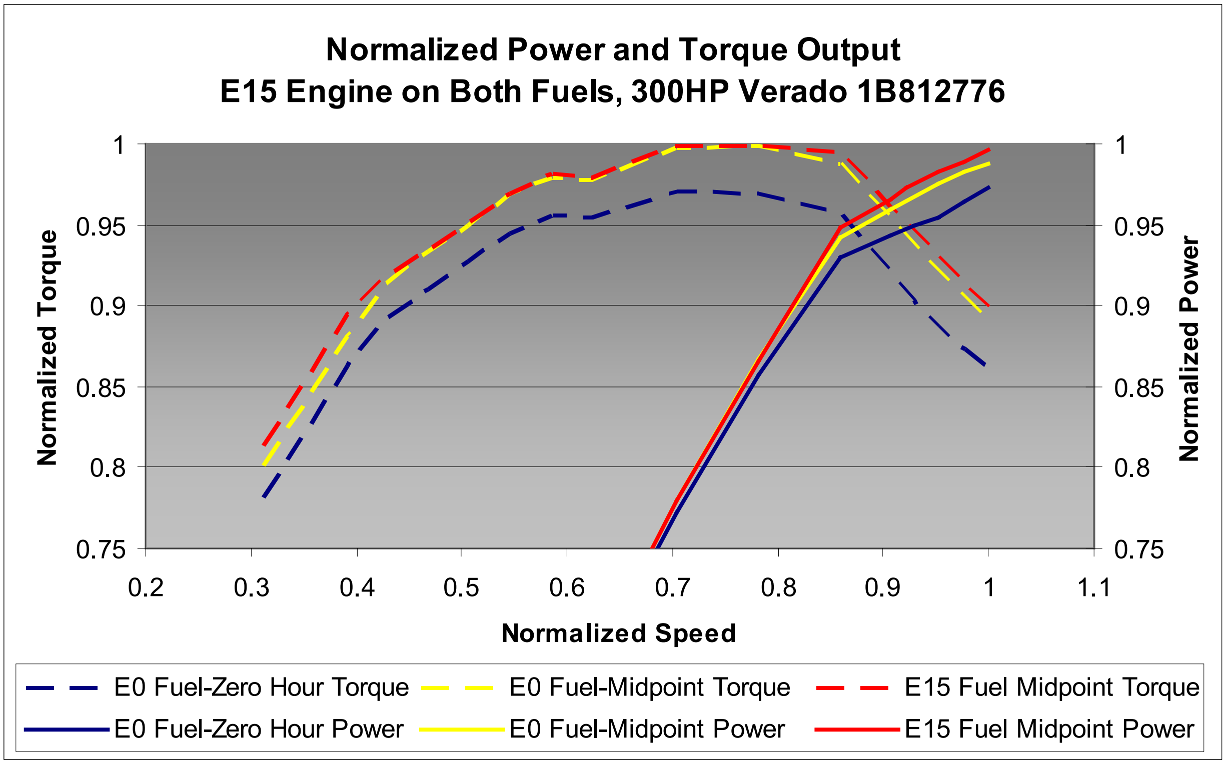


Figure 39: E15 Engine Power and Torque Output at Endurance Check Intervals-EEE-E0 and E15 Fuel

Figure 40 shows the difference in exhaust gas temperatures during power runs at the midpoint check on the 2 different fuels. There was up to a 30°C increase in EGT when operating on E15 fuel.

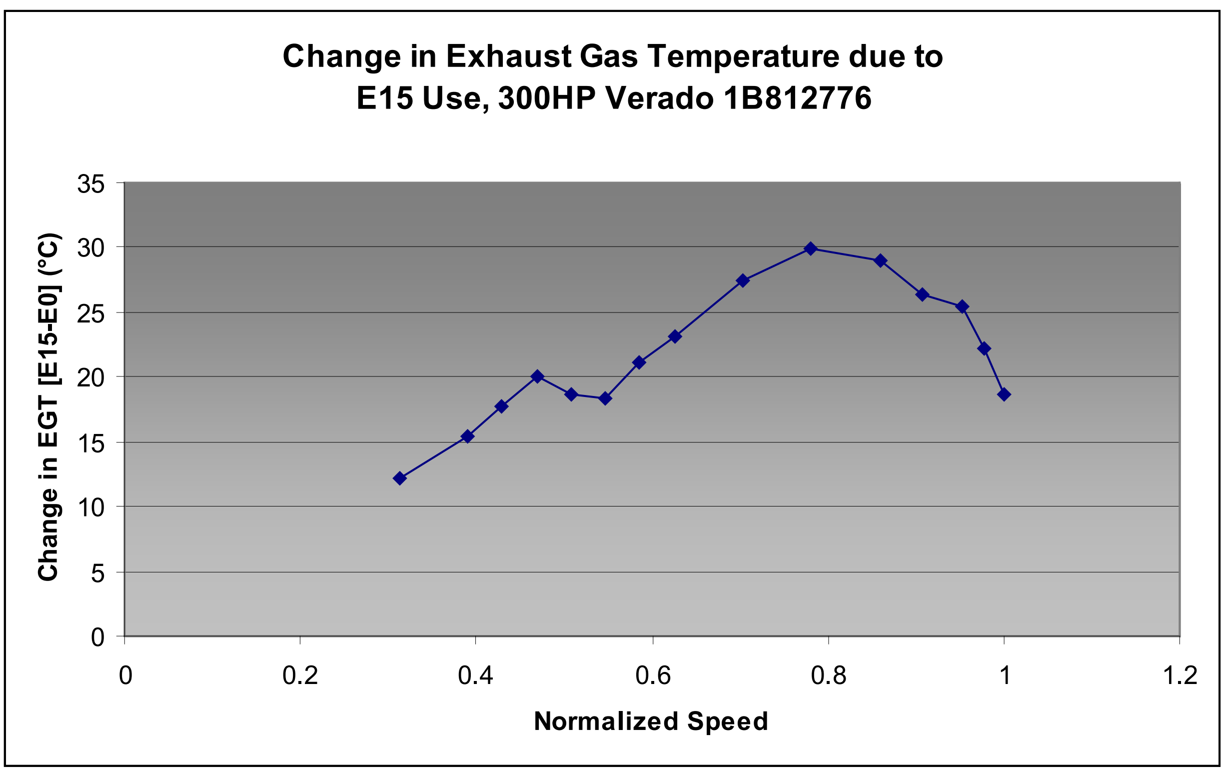


Figure 40: E15 Engine-Exhaust Gas Temperature Change at Wide Open Throttle, EEE-E0 to E15 Fuel

End of Test Teardown and Inspection

After all running engine tests were completed, the engines were disassembled and inspected. There was visual evidence that some of the internal components from the Verado E15 engine had experienced higher operating temperatures.

Upon disassembly, there were differences noted in the condition of the pistons from the 2 engines. Figure 41 shows pictures comparing the pistons from cylinder 2 from each engine. The piston from the E15 engine had a significantly higher amount of oil staining and carbon deposits than the piston from the E0 engine. The staining and deposits were noted on nearly every surface of the E15 piston compared with the E0 piston. Additionally, the pistons were sent to the metallurgy lab for hardness measurements. The hardness measurements were taken at several locations on the crown of the piston as well as a location on the internal portion of the piston just above the wrist pin bore after being sectioned. The average crown hardness of the E0 piston was 67.5 BHN (Brinell Hardness Number) while the E15 piston crown was 66.9 BHN. The internal piston hardness above the wrist pin bore was 74.1 BHN for the E0 piston and 71.5 BHN for the E15 engine's piston. Although the hardness measurements showed no effect of operating temperature on material properties, differences in visual appearance suggest that the E15 pistons operated at higher temperatures during running than the E0 pistons.

Figure 41: Piston Carbon Deposit Comparison, Cylinder 2, E0 on Left, E15 on Right

Figure 42 shows the small end of the connecting rods from each engine. The carbon deposits indicate that the E15 rods likely ran at higher operating temperatures. The carbon deposits on the rods are consistent with the carbon deposits observed on the pistons.

Figure 42: Connecting Rod Carbon Deposit Comparison, Cylinder 2, E0 on Left, E15 on Right

The exhaust valves were also closely inspected on the substitute E0 engine in order to compare with the valves that cracked on the E15 engine. With 372 hours of endurance aging time accumulated, no cracked valves were discovered during inspection under a microscope. The average hardness values of the exhaust valves from cylinder three of the E0 engine were 37.3 and 37.7 HRC. These values were consistent with other engines that were operated on E0 as indicated in Table 4.

During disassembly, the E15 engine was noted as having base circle contact on several of the exhaust cam lobes as noted above. The exhaust cam lobes from the substitute E0 engine did not show signs of base circle contact. The lash measurements shown in Figures 32 and 33 support these observations. A picture showing the difference in wear on the base circles of the exhaust cam lobes can be seen in Figure 43. The picture shows the E15 exhaust cam on the right and the E0 cam on the left. The wear pattern on the E15 exhaust cam lobe is apparent.

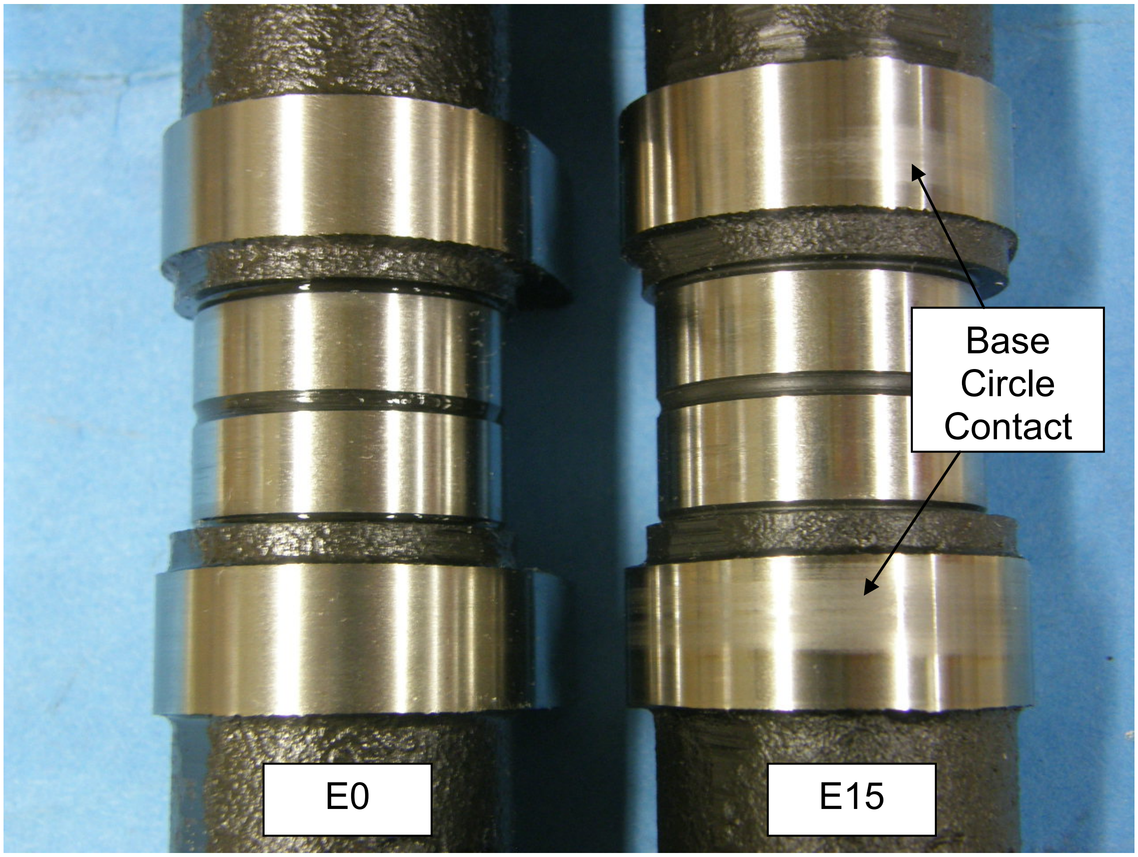


Figure 43: Exhaust Cam Lobe Base Circle Detail, Cylinder 3, E0 on Left, E15 on Right

200 EFI Two-Stroke:

Endurance Test Results

An engine failure prevented successful completion of the full endurance period for the 200 EFI E15 engine. The 200 EFI E15 engine failed a rod bearing before the completion of the endurance test. The 200 EFI E0 engine completed the 300 hour endurance test and all post-endurance dynamometer tests.

The E15 endurance engine failed at 283 total engine hours and had accumulated 256 hours of WOT endurance at the time of failure. Upon inspection it was found that the big end connecting rod bearing had failed on cylinder 3. The rod cap was still bolted to the rod after the failure. This engine family uses a fractured rod cap design with a roller bearing (typical for a two-stroke vs. a plain bearing in a four-stroke). Images of the remaining bearing cage and the damaged rod along with undamaged pieces for reference are shown in Figure 44. No rollers were found during teardown and were likely ejected from the bearing and made their way through the power cylinder and out the exhaust. There was extensive damage to the top of the piston on cylinder 3 indicating that the rollers went through the power cylinder. Due to the extensive damage to the bearing and connecting rod (since it failed at rated speed, full power) and the fact that not all of the pieces were recovered, root cause of the bearing failure was not conclusively determined. Little is known about the effects of ethanol blends on oil/fuel mixing and dispersion on total loss lubrication systems, such as the one on this engine family. More investigation is needed to understand if ethanol would negatively impact the lubrication systems on two-stroke engines.

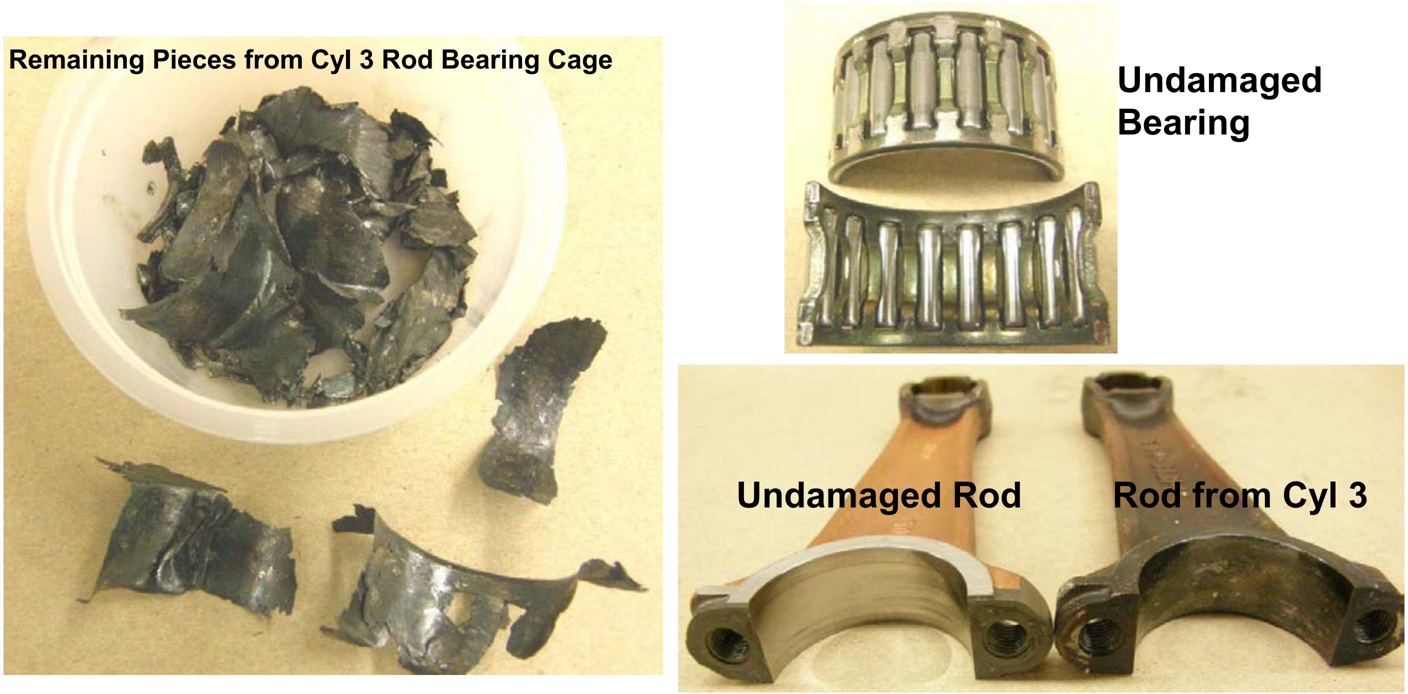


Figure 44: 200HP EFI Bearing Failure Pictures

Emissions Testing Results

As a result of the engine failure, a complete set of emissions data was not collected on the 200 EFI. However, conclusions can be drawn from the data that were collected. Figure 45 shows a summary of HC+NOx results from the emissions test on both engines. As Figure 45 shows, there was more variability in the E0 engine than on the E15 engine. E15 fuel did not have a detrimental effect on emissions degradation on this engine family. It is worth noting that of the roughly 120 g/kw-hr of HC+NOx, the NOx contribution is approximately 2 g/kw-hr. Since the HC is roughly 98% of the total HC+NOx, graphs depicting the changes in the individual constituents were left out of this report. The relative enleanment from the E15 fuel did slightly increase the NOx emissions, but that was not significant in comparison with the HC contribution.

The CO emission results from the 200 EFI engines are shown in Figure 46. The E15 fuel resulted in lower CO emissions, as expected due to the relative enleanment from the difference in fuel chemistry. Both engines and both fuels showed the same trend of increasing CO with more endurance time.

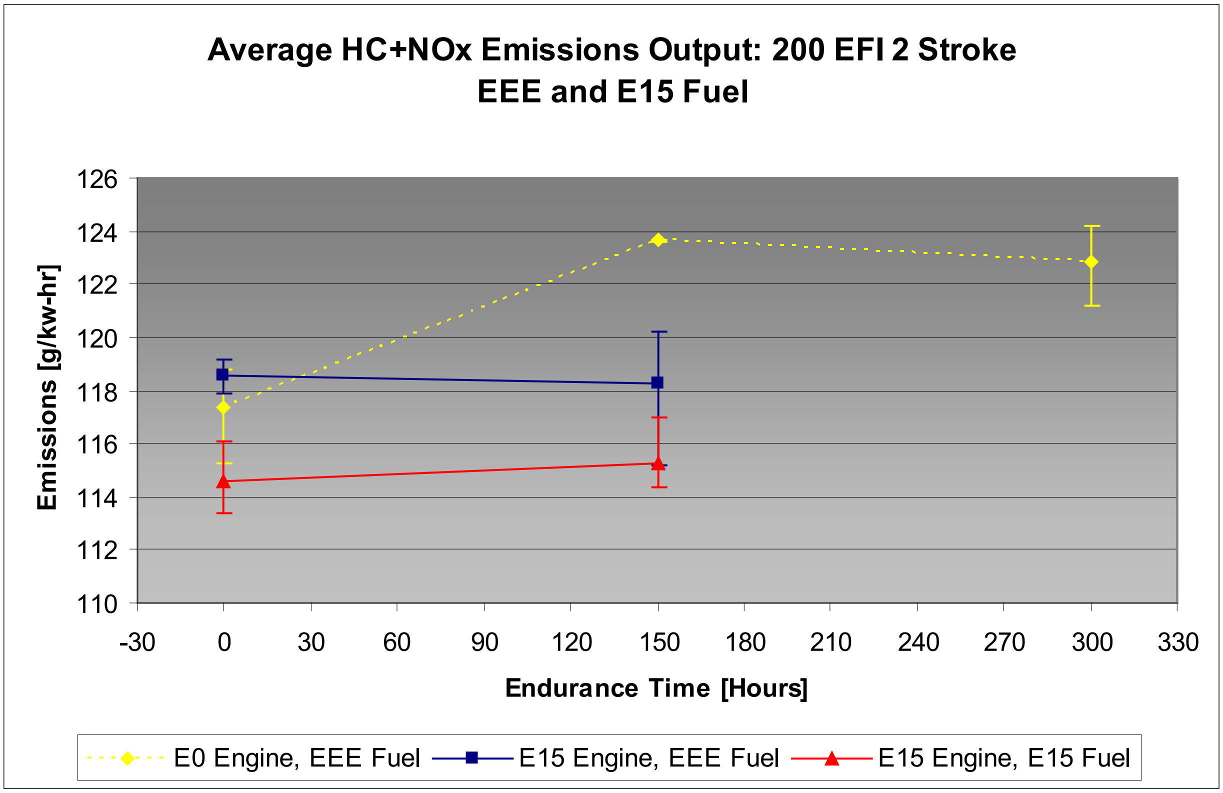


Figure 45: 200HP Two-Stroke HC+NOx Emission Results Summary

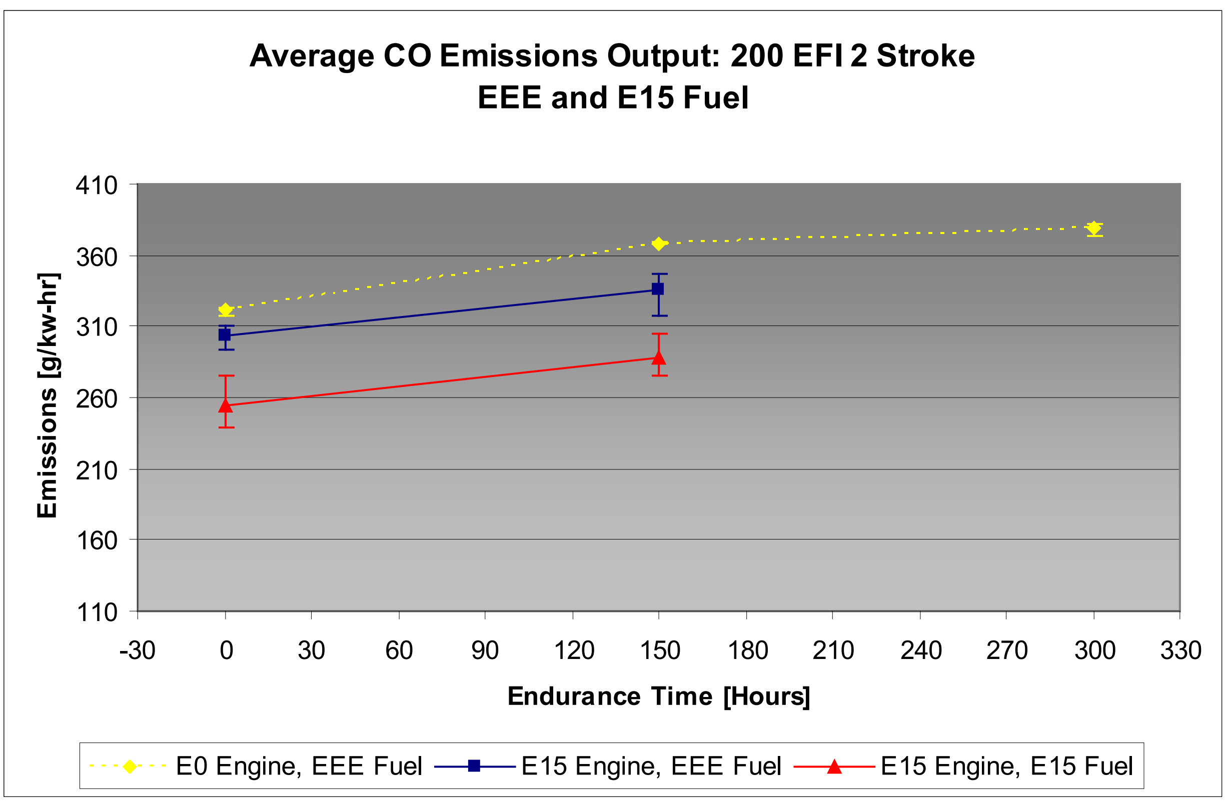


Figure 46: 200HP Two-Stroke CO Emission Results Summary

Engine Performance Comparison

The power and torque data (corrected per ISO 3046-1) from the E0 200HP EFI engine are shown in Figure 47. There were slight differences in the curves, but the changes from zero hours to 300 hours were less than 1% for both peak torque and peak power.

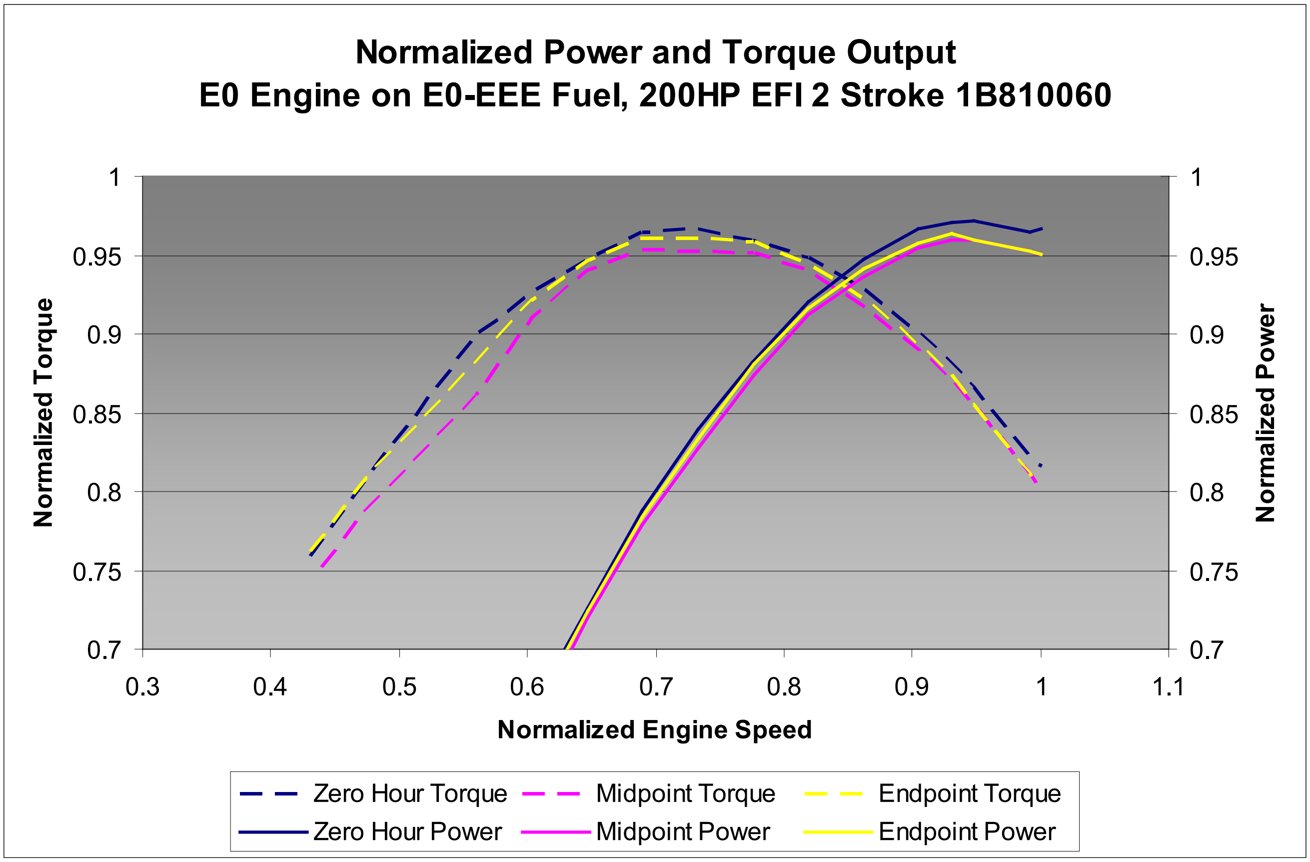


Figure 47: E0 Engine Power and Torque Output at Endurance Check Intervals-EEE-E0 Fuel

Data for the E15 engine on both EEE-E0 fuel and E15 fuel are shown in Figure 48. A comparison of the output at the zero hour and 150 hour checks are included. Similar to the E0 engine, there was less than a 1% change from the zero hour check to the 150 hour check for both the peak torque and peak horsepower for either fuel. There was an increase of approximately 2% in both peak torque and peak power when changing from E0 to E15 fuel. The engine may have been operating in a range closer to the Lean Best Torque on the E15 fuel due to the enleanment from the fuel change and/or the volumetric efficiency may have been better due to the additional charge cooling of the ethanol fraction. Figure 49 shows the difference in exhaust gas temperatures during the same power runs on the 2 different fuels. Since this was a 6 cylinder engine and individual cylinder measurements were possible, the average and maximum changes in EGT were plotted for clarity. On average use of the E15 fuel resulted in a 15-20°C increase in EGT in the range of frequent steady-state operation (>4500 RPM). The maximum increase in EGT for any individual cylinder when using E15 was 28°C.

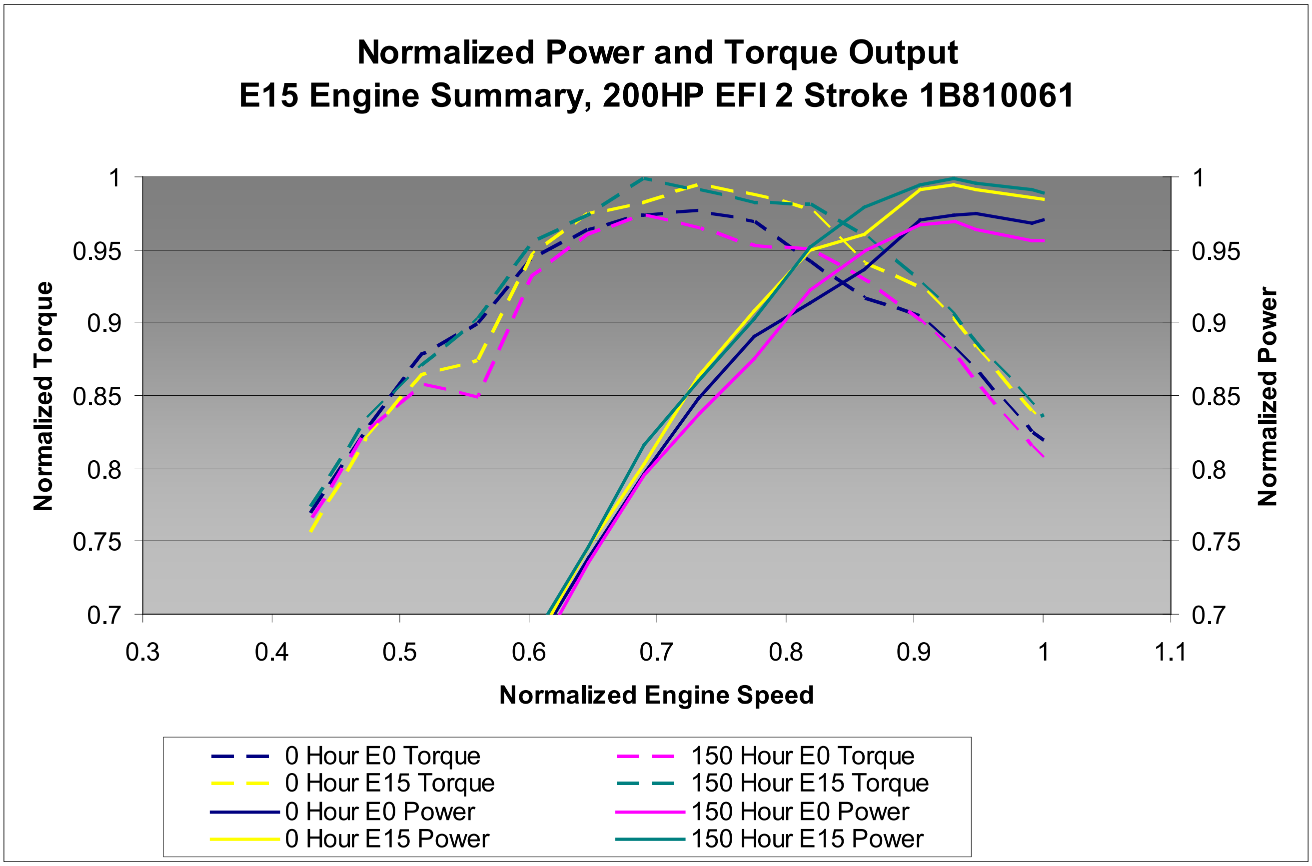


Figure 48: E15 Engine Power and Torque Output at Endurance Check Intervals-EEE-E0 and E15 Fuel

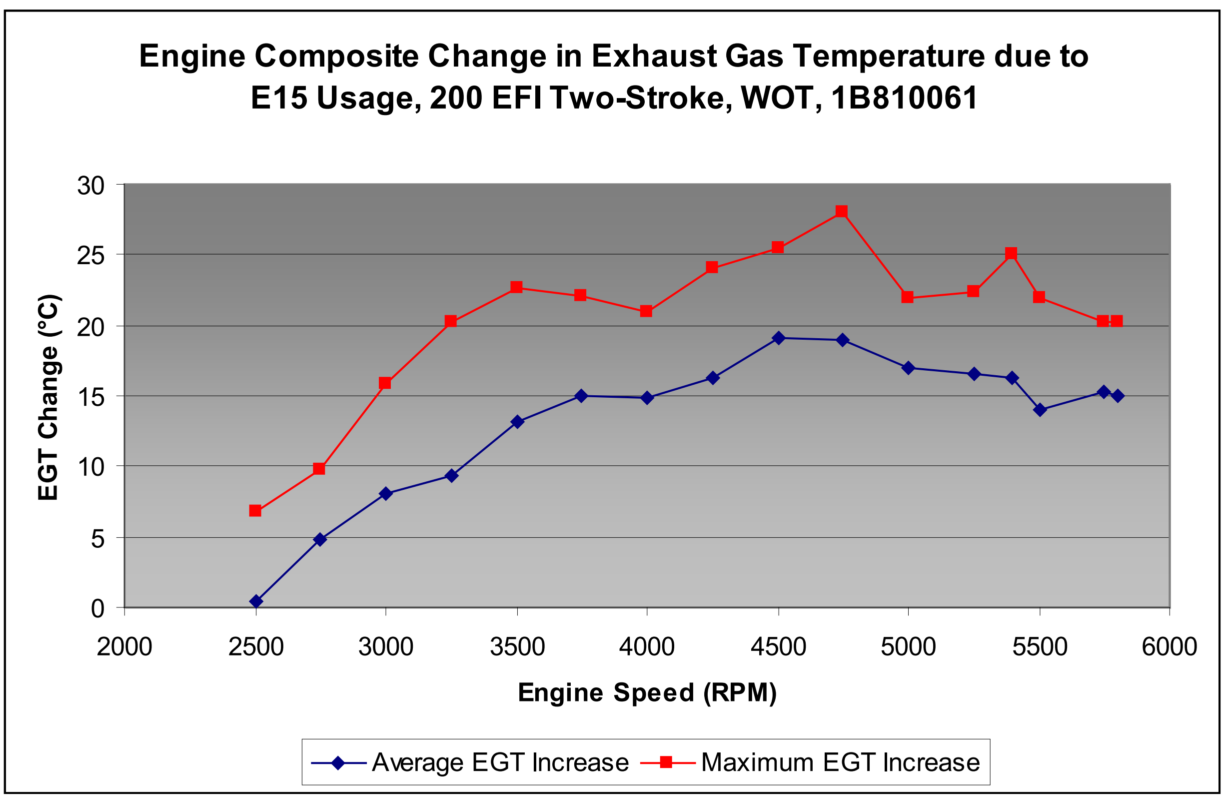


Figure 49: E15 Engine-Exhaust Gas Temperature Change at Wide Open Throttle, EEE-E0 to E15 Fuel

End of Test Teardown and Inspection

As was the case for the other engine families, the main areas of focus during teardown were looking for signs of wear and also material compatibility issues. Visual inspection of the components of the 2 engines did not suggest significant differences between them (aside from the rod bearing failure). In particular, the bore finish, carbon deposits, bearings from the small and big end of the rod, and main bearings were inspected for signs of mechanical or thermal distress and accelerated wear. No significant differences were noted aside from slight differences in the appearance of the wrist pins, as shown in Figure 50.

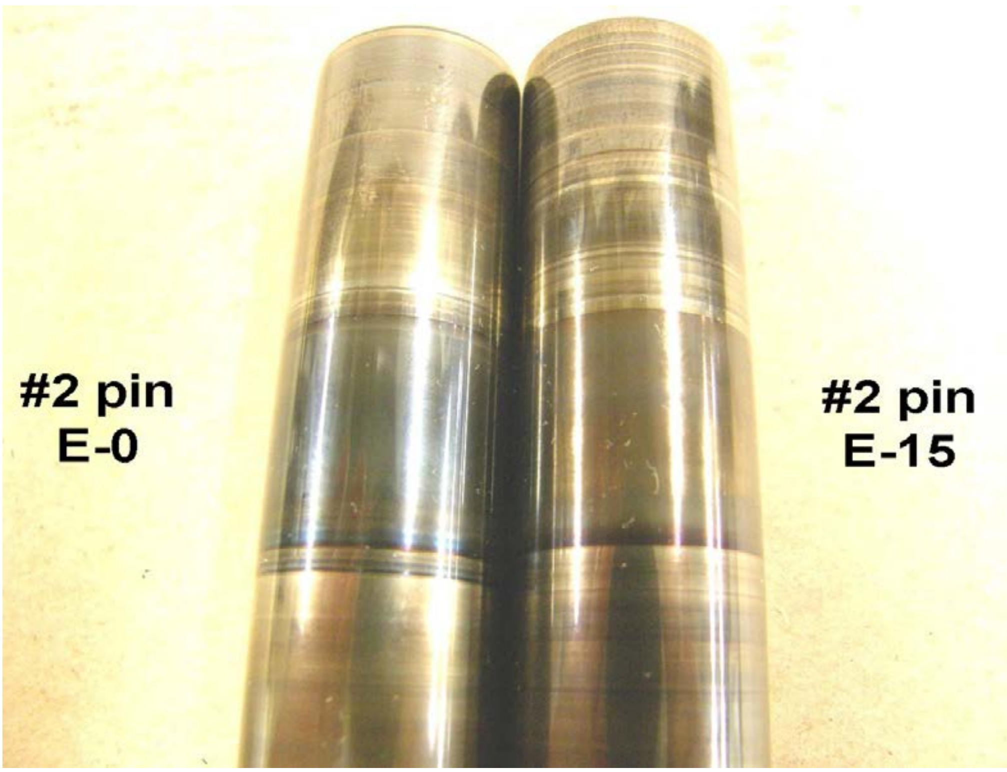


Figure 50: Cylinder 2 Wrist Pin Comparison, E0 on Left, E15 on Right

To provide a more in-depth analysis, selected components were further inspected. Using the same techniques as applied to the 9.9HP four-stroke components, the pistons and wrist pins from cylinder 2 on the 200HP EFI two-stroke engines were checked for material hardness. The results can be seen in Table 5. There were no significant differences in the hardness between the wrist pins, but there was a slight difference in hardness of the pistons (6.3%). The lower hardness of the piston on the E15 engine suggested it may have been running at higher temperatures. The nature of two-stroke engines causes them to be very sensitive to piston fit/piston temperature. An increase in piston temperature caused by fuel differences could cause increased propensity for power cylinder failures for customers. The slight difference in hardness was near the limit of repeatability for the test method so the results should be considered an indicator only. More testing would be necessary to gain confidence with a statistically significant sample size.

Table 5: Hardness Measurements on Various 200HP EFI Two-Stroke Engine Components

2.5L 200HP EFI	Hardness Scale	**E0** 1B860010	**E15** 1B810061	Percent Difference
Piston Wrist Pin, Cyl 2	Rc	54.7	54.1	1.1%
Piston Crown, Cyl 2	BHN	63.0	59.0	6.3%

In addition, the high pressure fuel pumps from both engines were sent to the pump manufacturer for flow testing. There were no significant differences in pump output between the 2 pumps, and they were within expected flow ranges for end of life components.

Additional Testing

4.3L V6 Catalyzed Sterndrive Emissions Comparison

Since the E15 fuel and a catalyzed engine were both readily available in the test lab, additional testing was performed beyond the test program requirements. Emissions tests were performed on E0-EEE fuel and E15 test fuel to determine any immediate impacts of increased ethanol for this engine family. No durability testing was performed. The 4.3L V6 sterndrive engine (General Motors V6 that was adapted and modified for marine use) was equipped with closed-loop electronic fuel injection and exhaust catalysts. The standard calibration for this engine in Mode 1 operation (rated speed and power) was such that the engine ran rich of stoichiometric to control exhaust gas temperatures. This is a common engine control approach to protect components during high power operation. For the type of exhaust gas oxygen sensor used on this engine, rich operation allows for no feedback control of the fuel air mixture. As such, the engine ran open-loop at Mode 1. All other modes ran closed-loop. The 5 mode HC+NOx and CO emissions totals were lower on E15 fuel due to the fact that the engine ran approximately 4.5% leaner on the E15 fuel at Mode 1. The HC+NOx at Mode 1 changed from 1.18 g/kw-hr on EEE to 1.10 g/kw-hr on E15. This small reduction was driven by the reduction of HC emissions. The NOx emissions increased on E15, but not as much as the HC decreased, yielding an overall lower total. The CO at Mode 1 was reduced from 45.6 g/kw-hr on EEE to 29.8 g/kw-hr on E15. The reduction of CO was attributed to the leaner operation at Mode 1. The HC+NOx and CO values for the remainder of the mode points were essentially the same since the closed loop fuel control allowed the engine to run at the same equivalence ratio. See Figure 51 for details of the emissions outputs.

The leaner operation at wide open throttle (Mode 1) caused an increase in exhaust gas temperatures when operating on E15 fuel. The exhaust gas temperature increase across all 6 cylinders was approximately 20°C. The elevated EGT during WOT operation could cause valvetrain durability issues. The catalyst temperatures were approximately 32°C higher at Mode 1 with E15 fuel. This increase in catalyst temperature at WOT would likely cause more rapid deterioration of the catalyst system leading to higher exhaust emissions over the lifetime of the engine. The full impact of E15 on catalyst life would depend on the duty cycle of this engine in actual application. Typical duty cycles of marine engines include considerable amounts of time at WOT operation (open loop) so the catalyst temperature increase is of concern.

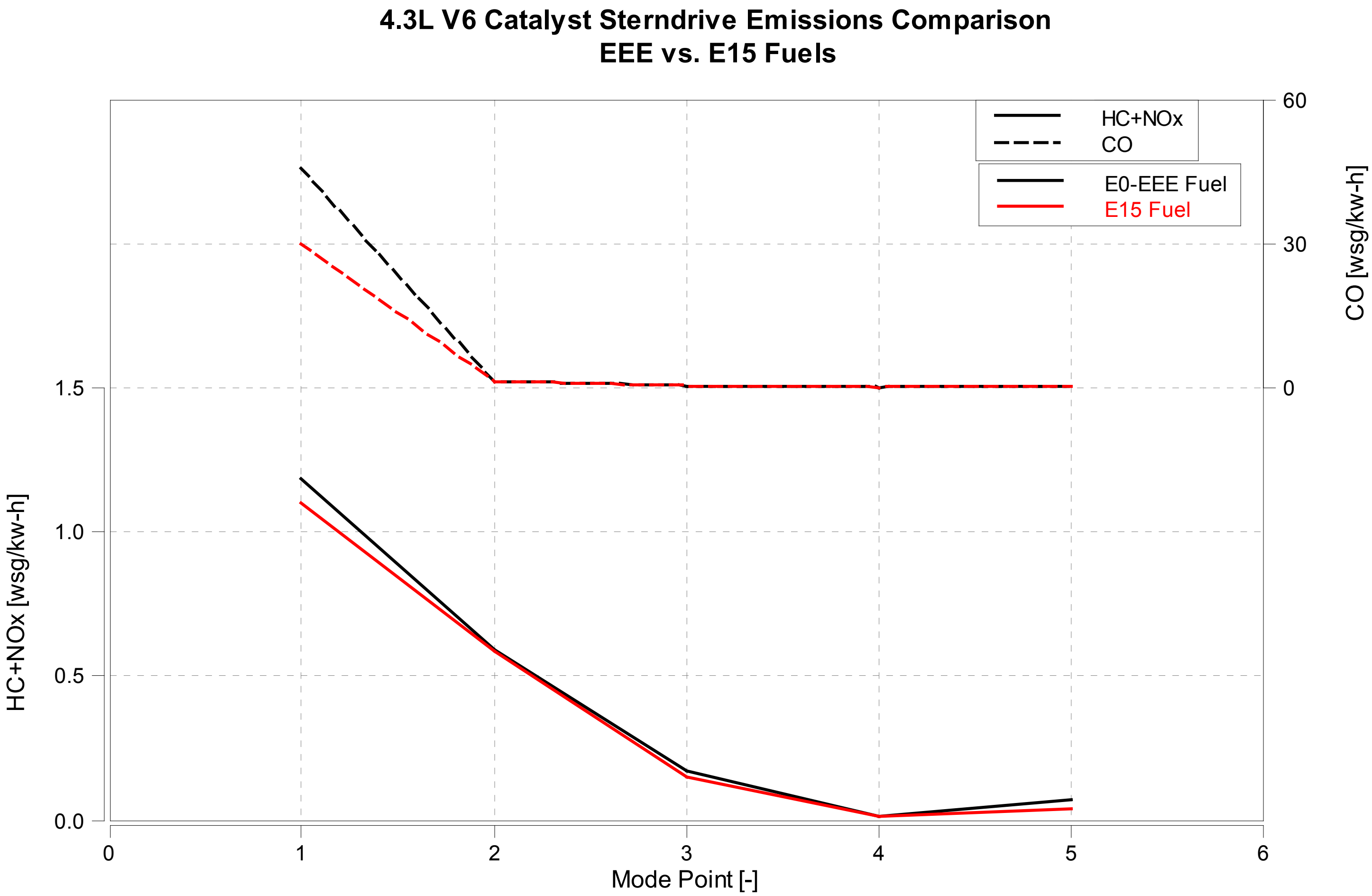


Figure 51: Emissions Comparison 4.3L V6 Catalyst Sterndrive, EEE vs. E15

The other aspect that was affected by running E15 on the closed-loop controlled engine was the fuel consumption. Since the closed-loop control system drove to an equivalence ratio, the fuel flow rate increased to account for the differences in fuel chemistry. Table 6 shows the fuel flow measurements by mode point along with the percent difference in fuel flow between the 2 fuels (positive values mean E15 fuel flow is higher). In closed-loop operation, the fuel flow increased 5.3% on average on E15 fuel. This increase in fuel flow causes concerns not just in fuel mileage, but also in useful range of the craft.

Table 6: Fuel Flow Comparison on 4.3L V6 Catalyst Sterndrive, EEE vs. E15

	EEE	E15	
Mode	Fuel Flow	Fuel Flow	Difference
	kg/hr	kg/hr	%
1	46.8	47.0	0.4%
2	24.2	25.5	5.3%
3	13.1	13.7	4.7%
4	7.1	7.5	5.2%
5	2.0	2.1	5.9%

Mode 2-4 Average 5.3%

Final Summary

Summary of Results:

EPA's recent announcement of a partial waiver approving E15 fuel for use in 2001 and newer cars and light trucks[9] will create an opportunity for consumers to misfuel their marine engines. This program indicates that misfueling currently available marine outboard engines may cause a variety of issues for outboard engine owners. These issues included driveability, materials compatibility, increased emissions, and long-term durability. There were also 2 examples of how the ethanol fuel caused an increase in fuel consumption.

9.9HP Carbureted Four-Stroke:

The E15 engine showed high variability in HC emissions at idle during the emissions tests at the end of the 300 hour endurance period. Both the E0 control engine and E15 test engine ran leaner at idle and low speed at the end of the endurance test. When operated on E15 fuel after 300 hours of endurance, the lean operation at idle coupled with the additional enleanment from the E15 fuel caused the engine to exhibit misfire and poor run quality (intermittent misfire or partial combustion events). A misfiring engine would cause customer dissatisfaction due to the inability to idle the engine properly, excessive shaking, and hesitation or possibly stalling upon acceleration. As it relates to this study, the misfire caused an increase in HC emissions at idle. This increase in HC variability at idle caused the average total HC+NOx to increase from the start to end of endurance, whereas the HC+NOx on E0 fuel on both engines showed a decreasing trend. As expected, the CO emissions were reduced when using E15 fuel due to the leaner operation.

The power and torque output of the E15 engine was higher with E15 fuel than with E0 fuel. The power and torque output of the E0 control engine increased slightly with more endurance time. The power and torque output of the E15 test engine showed a flat or declining trend with more endurance time.

The end of test inspection showed evidence of elevated temperatures on base engine components due to the lean running on E15 fuel. There were significantly more carbon deposits on several components of the E15 engine, indicating that these parts likely had higher metal temperatures during operation. Hardness measurements indicated that the pistons had higher operating temperatures on the E15 engine. The exhaust gas temperature increased 17°C at wide open throttle as a result of the leaner operation on E15 fuel.

The fuel pump gasket on the E15 engine also showed signs of deterioration compared with the E0 engine after approximately 2 months of exposure to E15 fuel.

300HP Four-Stroke Supercharged Verado:

The E15 Verado failed 3 exhaust valves prior to completion of the endurance test. One valve completely failed and 2 others had developed significant cracks. Metallurgical analysis showed that the valves developed high cycle fatigue cracks due to excessive metal temperatures. The majority of exhaust valves on the E15 engine lost a significant amount of lash which may have contributed to the observed valve failures. The exhaust gas temperature increased 25-30°C at wide open throttle due to the lean operation with E15 fuel.

In addition to the elevated temperatures on the exhaust valves, the pistons showed evidence of higher operating temperatures. The carbon deposit differences indicated that the E15 engine's pistons were hotter during operation.

The E15 Verado generated HC+NOx values in excess of the Family Emissions Limit when operated on E15 fuel, but did not exceed the limit when operated on EEE-E0. The primary contributor to the increase in exhaust emissions was the NOx due to enleanment caused by the oxygenated fuel. The CO emissions were reduced when using E15 fuel due to the leaner operation, as expected.

At emissions mode point 3, the lean combustion due to the E15 fuel caused the engine to lose torque output due to operation significantly leaner than LBT. As a result of the torque loss, the throttle input had to be increased 10% to maintain the same torque output as on E0-EEE fuel. The change in throttle input caused an increase in fuel flow of 10%. Mode 3 is representative of a typical cruising speed and load. The E15 fuel would cause the fuel consumption to be 10% higher at that operating point for a customer.

200HP EFI 2.5L Two-Stroke:

The 200HP EFI two-stroke engine showed no signs of exhaust emissions deterioration, though the emissions output after the full endurance testing was not measured due to a failure of the E15 engine. The primary driver of the HC+NOx emissions on this engine family was HC (approximately 98% of the HC+NOx total). As expected, since the E15 fuel caused the engine to run lean, the HC emissions were lower, as were the CO emissions. There was more variability of HC+NOx observed on the E0 engine than the change in emissions on the E15 engine. The deterioration of the CO emissions had similar trends between the 2 engines.

The endurance test of the E15 engine was stopped short of the 300 hour target due to a connecting rod bearing failure on cylinder 3. The root cause of the bearing failure could not be identified. More testing is necessary to understand the effects of ethanol on two-stroke engine lubrication mechanisms where the oil and fuel move together through the crankcase. The E0 engine completed the entire 300 hours of durability testing.

Other than the bearing failure, the end of test teardown and inspection did not show any visible significant difference between the 2 engines. Hardness checks performed on the pistons of both engines indicate that the E15 engine may have had higher piston temperatures, a concern on two-stroke engines where higher temperatures could lead to more power cylinder failures. The exhaust gas temperature increased 15-20°C on average due to the lean operation with E15 fuel.

4.3L V6 EFI Four-Stroke Catalyzed Sterndrive

Since E15 fuel was readily available in the test facility and an engine equipped with exhaust catalysts was on the dynamometer, emissions tests were conducted on a 4.3L V6 sterndrive engine. No durability testing was performed. At rated speed and wide open throttle the exhaust gas temperatures increased by 20°C on average and the catalyst temperatures increased by 30°C. This increase in catalyst temperature would likely cause more rapid aging and deterioration of the catalyst system at WOT. The overall effect of the increase in deterioration rate would be duty cycle dependent. The HC and CO values decreased at the Mode 1 (rated speed, rated power) emissions test point, which is an open loop operating point, due to leaner operation with E15 fuel, as expected. The fuel consumption increased by 4.5% at the operating points that were running in closed-loop fuel control.

Recommendations:

This test program was limited in scope in terms of operating conditions. More investigation is necessary to understand the effects over a broader range of conditions. Ethanol's effects on part load operation, cold start, hot restart/vapor lock, and overall driveability need to be evaluated. The wide range of technology available for marine engines due to the wide range of engine size will complicate this issue significantly. Mercury Marine produces engines from 2.5HP-1350HP with a wide array of technologies ranging from two-stroke or four-stroke; carbureted, EFI, or direct fuel injected; naturally aspirated, supercharged, or turbocharged; and more.

Ethanol's ability to absorb water into the fuel is of paramount concern for the marine market and this issue has not been addressed in this test program. The contaminants that water can bring with it, potentially saltwater, can cause severe corrosion in fuel systems. A leak or fuel system failure could cause the engine to be inoperable and leave the vessel stranded, which would obviously be a major dissatisfaction to the customer. In addition, a better understanding of the effects higher ethanol blends have on marine fuel systems in terms of materials compatibility and corrosion is needed. Marine vessels tend to have very long storage durations, can be stored in very humid environments, and will have more opportunities to have fuel system exposure to water, including saltwater.

More testing is needed to understand how ethanol blends affect oil dispersion in two-stroke engines that have fuel and oil moving through the crankcase together. Ethanol tends to be a good solvent and may break down lubrication at critical interfaces by cleansing these surfaces of the residual oil film.

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