Preliminary Comments
on the DOE 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) –
Biographical Information Attached as Exhibit A

I. OVERVIEW

The comments below focus exclusively the recent limited tests performed by DOE (NREL and ORNL) on Small Non-Road Engines (SNRE), including lawn, garden and forestry products, like lawnmowers and trimmers.

My enclosed prior technical paper from June 2007 provides a broader and more comprehensive analysis of all the potential adverse impacts of mid-level ethanol fuels when used to operate lawn, garden and forestry products. (See Exhibit B). As explained below, the new DOE report does not address or evaluate most of these outstanding problems or concerns. It is well-established that ethanol fuels generally permeate at significantly higher rates through certain plastics, nylon, and rubber materials used in fuel tanks and system. However, DOE did <u>not</u> conduct any emissions testing pertaining to evaporative emissions. Evaporative emissions (from fuel tanks, fuel lines and engines) in small engines and equipment are now regulated by EPA. (See Exhibit B at p. 14).

It is well-established that E15 and E20 fuels may degrade or distort components in small engines, leading not only to "operational issues," but also to durability, emissions, and safety impacts. (See Exhibit B at p. 7-8). However, DOE did not conduct any "materials compatibility" testing (or generate any related results) on whether nylon, rubber, plastic, or metal materials (in the affected fuel systems) may be degraded or distorted by mid-level ethanol fuel.

II. THE DOE 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.

III. 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).

IV. DEFICIENCIES IN THE TESTING PLAN AND SCOPE

A. 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.*

B. 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.

C. 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.

D. 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.

V. 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 DOE 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. (See Tables A and B to Exhibit B). 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.

VI. 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.

EXHIBIT A

EXHIBIT A
Biographical Sketch

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EXPERIENCE SUMMARY

Dr. Sahu has a Bachelors of Technology (Mechanical Engineering) degree from the Indian Institute of Technology (IIT, Kharagpur) as well as a M.S/Ph.D in Mechanical Engineering (Combustion) from the California Institute of Technology (Caltech).

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.

EXHIBIT B

Technical Paper On The Introduction of Greater Than E10-Gasoline Blends

by

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1.0 Introduction

Recent debates driven by issues ranging from reducing dependence on foreign oil, reducing global climate change impacts, reducing the rapid escalation of gasoline prices at the pump, and even improving national security have resulted in the call to increase the proportion of renewable fuels available to users. In particular, there have been marked calls to rapidly increase the proportion of ethanol (ethyl alcohol) in gasoline. The current gasoline pool in the U.S. contains anywhere from 0% by volume (E0) to 10% by volume of ethanol (E10) depending on time of year and location. A mix of 85% ethanol in gasoline (E85) is also available as a motor fuel for vehicles that are capable of using the fuel. There are several efforts underway to statutorily increase the E10 proportion to greater than 10%. In particular, Minnesota has targeted 20% ethanol in gasoline as the goal for fuel for the conventional market, and legislators in other states have attempted to mandate 30% and 50% ethanol blends.

At first glance, increasing the ethanol content from 5-10% to higher levels in gasoline does not seem like a very radical idea. Assuming ethanol availability, proponents argue that it should be easy to implement and will help meet several policy goals. The argument goes as follows: all current engines and equipment fuel systems that run on gasoline already run successfully on E5-E10. Thus, why should there be any additional difficulty in increasing the ethanol content in gasoline? Further, proponents ask why there should be difficulties if others (particularly Brazil) have been able to make the switch to greater than E10. Surely all technical issues should have already been addressed. These lines of reasoning, however, are overly simplistic. They fail to properly consider the interaction of these proposed fuels with a large and extensive existing (or legacy) fleet of over 300 million pieces of equipment and vehicles that have to run successfully on the fuel they are given but are designed to run only on gasoline containing up to 10% ethanol. They also fail to consider the peculiar chemistry and physical properties of ethanol-gasoline mixtures and how these can dramatically affect the transportation, storage, combustion, and emissions of such fuel mixtures. These technical issues are not intuitive. This paper will discuss some of these key technical issues that need to be carefully considered before allowing greater than E10 in the conventional U.S. motor gasoline pool. Finally, it should also be noted that

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[1] A short biographical note on the author is provided in Attachment A. He can be contacted at the e-mail above or by phone at 626-382-0001.

many engines and products are built for global distribution and fuel mix changes in the U.S. can have impacts on how such products have to be designed and distributed in the future.

2.0 Description and Diversity of Affected Equipment

A primary focus of this paper is the impact of greater than E10 fuels on the existing pool of equipment that will need to use this fuel. Broadly, this pool consists of on-road equipment – mainly automobiles and motorcycles - and off-road equipment – which ranges from the smallest hand-held 2-stroke chainsaw to large off-road machinery and from lawn-mowers to personal watercraft. Table A contains a list of the various types of off-road equipment that are designed for and run on conventional gasoline.

There is a vast amount of diversity in the existing gasoline-using vehicle and equipment population that, altogether, can be categorized based on the following:

- Use (e.g., lawn and garden; marine; snowmobiles, transportation, etc.)
- Engine Size (e.g., displacement ranging from less than 20 cc to 6000 cc)
- Expected Useful Life (50 hours or less to 10,000 hours)
- Engine Design
    - Air or water cooled
    - 2-Stroke, 4-Stroke, or hybrid (2/4 Stroke)
    - Side-valve or overhead valve
    - Variable valve timing
    - Intake air charging – superchargers, turbochargers, etc.
- Fuel Injection Technology
    - Carbureted – float-type, diaphragm type, single and multi-circuit
    - Fuel Injection –multi-port, direct, etc.
- Control Technologies
    - Open loop
    - Closed loop
- Fuel Systems
    - Variety of tank and hose materials
    - Various evaporative control strategies for permeation and tank venting
    - Various design considerations such as for multi-positional use
- Emission Control Systems
    - Engine modifications
    - Three-way catalysts and oxidation catalysts (2-stroke engines)
    - Exhaust gas sensors and diagnostic systems

- Feedback systems

Considering all of the above, from a cost standpoint, on-road and off-road equipment can range from a $50 hand held blower all the way to a $100,000+ automobile or a piece of construction equipment.

The existing population of automobiles in the U.S. is estimated at close to 200 million units. The existing population of off-road equipment is around an additional 100 million. Assuming an average resale price of $10,000 for an existing car/truck and an average cost of $500 for existing off-road equipment, the nominal asset value that is represented by existing equipment is over 2 trillion dollars. Should this equipment be damaged and need to be replaced, the replacement costs would be even greater. The average American family possesses, in addition to 2 cars/trucks, several pieces of off-road gasoline-powered products ranging from lawn and garden equipment to recreational equipment. It is not an exaggeration to note that almost every American household has significant on-road and off-road equipment assets.

3.0 Fuel and Equipment Form a Single System

Another point that should be made is that the on-road and off-road equipment are designed from the very outset with a particular fuel or fuel range in mind. The performance or driveability,[2] durability, and emissions can only be assessed when the combined fuel and equipment is considered to be a single, combined, system. Equipment is rarely designed (or can rarely be economically designed in these very competitive markets) to anticipate a wide range of fuel properties. Fuel specifications, therefore, are very important, both to the manufacturer of the equipment and to the user.

4.0 Ethanol and Ethanol-Gasoline Mixture Properties

Ethanol has been used in the U.S. as a gasoline fuel additive since the late 1970s when it was used as a fuel extender due to gasoline shortages after the oil embargo as well as an octane enhancer since it improved the anti-knock performance of gasoline. In the early 1990s, the federal government began to require 2% oxygen by mass in the gasoline used in certain parts of the country to reduce smog. In this decade, when many state governments prohibited the use of the predominant oxygenate, MTBE,[3] ethanol then became the oxygenate of choice. Several states also have required ethanol use in winter (“gasohol”) as a way to reduce carbon monoxide emissions.

Some (but not all) of the changes in fuel properties due to the addition of ethanol to gasoline include:

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[2] Based on years of research, good driveability is generally considered to include the following: quick starting, stall-free engine warm up, smooth idle, hesitation-free response to throttle, surge-free operation during cruise, and freedom from vapor lock. Driveability is rated at idle, during acceleration, and under cruise or normal operating conditions as the car/equipment engine is driven through a prescribed cycle.

[3] States started banning MTBE (methyl tertiary butyl ether) after leaking underground fuel storage tanks caused it to be found in groundwater.

- Change in octane number
- Change in fuel volatility (as measured through several properties, including vapor pressure, vapor-liquid ratio, and the temperature-distillation curve)
- Change in the energy density
- Change due to the oxygen content
- Effect on water solubility and phase separation

These property changes can affect performance, emissions, or both. Ethanol also may affect the fuel's compatibility with various materials, which means it can affect the product's durability.

4.1 Change in Octane Number

In general, addition of ethanol up to a certain amount improves gasoline's octane number due to its excellent anti-knock properties. Engines specifically designed to use high octane fuels, such as high performance engines, may use higher compression ratios or increase charge air compression to increase power output.

4.2 Change in Fuel Volatility

A fuel's ability to vaporize is referred to as its volatility. It is represented by several measurements, including vapor pressure, vapor-liquid ratio and the amount vaporized at different temperatures (distillation). The vapor pressure of the fuel, which is very important from both an emissions and performance standpoint, may be the property most familiar to the public. Typically, refiners optimize and maintain vapor pressure in a given range for performance, business, and regulatory purposes. If the vapor pressure of the fuel is too low, that may cause problems in starting engines in cold temperatures; if it is too high, it may cause vapor lock at high temperatures. In either case, the driver or operator will experience performance problems.[4] High vapor pressure and the presence of ethanol also increases evaporative/diffusional emissions (and fuel loss) as well as higher permeation losses.[5]

The vapor pressure of ethanol is lower than that of gasoline. However, the addition of ethanol to gasoline, especially at lower concentrations, can actually increase the vapor pressure of the mixture to greater than that of gasoline. It depends on the amount of ethanol added and the composition of the base gasoline.[6] For blends using a base gasoline with a vapor pressure of 9

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[4] 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.

[5] Permeation is a process that is not yet fully understood; other factors besides vapor pressure also likely play a role in permeation rates.

[6] Gasoline is a mixture of several different molecules, and its composition can vary widely.

psi, the vapor pressure increase reaches a maximum around E5, and then slowly starts to come down with further increase in ethanol concentration.[7]

So, what is the effect of ethanol/gasoline blends on engine performance? Gasoline does not ignite as a liquid, only as a vapor. There must be sufficient fuel vapor present inside the combustion chamber to initiate and sustain combustion, i.e., to get the engine to start. This vaporization is governed by the fuel's overall volatility, measured by its distillation curve. Within a certain temperature range (that varies with each blend), ethanol decreases the temperature at which the fuel vaporizes, which, theoretically, should help combustion. However, ethanol blends also require more heat to vaporize than gasoline, which means that less vapor than predicted by the distillation curve is actually present inside the cylinder. For example, E10 requires over 15% more heat to vaporize than gasoline. Thus not only the distillation percentage versus temperature, but the heat input required to achieve the temperature are important to understand how fuel differences will interact with the engine design and the operating conditions. Current fuels are formulated to address this phenomenon. These fuel formulations allow the fuel blend to provide the desired amount of fuel vapor at the temperatures and air pressures typically found in engines to provide the expected starting and hot engine operation characteristics.

Other concerns about low temperature fuel characteristics of 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.

The primary fuel-related concern that occurs at elevated ambient temperatures is vapor lock. Vapor lock is a condition where the fuel in the engine's fuel delivery system vaporizes preventing the required volume of fuel to be delivered. 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.

4.3 Change Due to the Enleanment Effect of Ethanol

Gasoline is a mixture of many hydrocarbon compounds that consist mainly of hydrogen and carbon.[8] 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. 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

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[7] American Petroleum Institute (API), Alcohol and Ethers: A Technical Assessment of Their Application as Fuels and Fuel Components. API Publication 4261, Third Edition. June 2001.

[8] Sulfur, nitrogen, and trace elements also may be present.

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. The effect of this type of fuel change on an engine is called “enleanment.”

The effect of enleanment depends on engine design and how fuel is metered into the engine. Since the early 1980s, most automobile engines in the U.S. have used some form of "closed loop" fuel system that continuously monitors and adjusts the amount of fuel delivered to the engine to maintain the stoichiometric air-to-fuel ratio. These vehicles have adjustment ranges that can accommodate oxygenated fuels and, when operating in the "closed loop" mode, may not experience any adverse effects from oxygenated fuels once they have reached operating temperature. Even these vehicles, however, during cold start and at full throttle, can operate in an "open loop" mode that provides a rich fuel mixture that is necessary for these conditions and to allow the control system to achieve operating temperatures. In the rich mixture, "open loop" mode, vehicles can experience enleanment effects from the oxygenated fuel. While most on-road engines have closed-loop systems, most off-road engines do not. Thus, they have no way to compensate for this enleanment condition. Lean operation can have several negative attributes including higher combustion temperatures. Even with closed-loop systems, if the fuel contains an amount of ethanol that is outside the system design, the engine similarly may receive too much oxygen and experience performance problems. Additional Orbital test reports[9] discuss the performance issues associated with on-road vehicles and off-road equipment using E20 fuels.

4.4 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. 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.

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[9] Orbital Engine Company Reports: (a) A Literature Review Based Assessment on the Impacts of a 20% Ethanol Gasoline Fuel Blend on the Australian Vehicle Fleet, November 2002; (b) Market Barriers to the Uptake of Biofuels Study Testing Gasoline Containing 20% Ethanol (E20) Phase 2B Final Report, 2004.

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.

4.5 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 B 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. This is not an exhaustive list and is meant as an illustration of the diversity of materials used presently. The compatibility of all of these materials with greater than E10 fuel blends is currently unknown; little testing has been done because higher level blends are illegal for use in conventional products and vehicles, so there has been no reason to test. However, some test data is available from testing on E20 fuels by others.[10] Based on these studies, it is clear that several rubbers and elastomers can swell and deteriorate more rapidly in the presence of ethanol. Other materials, such as fluoroelastomers may be able to handle a range of ethanol blends. 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. 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.

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[10] 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.

As noted earlier, 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 than conventional gasoline.[11]

5.0 Effect on Emissions

Various studies have been conducted on assessing the effect of E5-E10 on engine exhaust emissions of NOx, hydrocarbons, CO, and other air toxics. Based on these, it is generally true that emissions of CO are reduced in the presence of ethanol due to the presence of the oxygen atom in the fuel. Exhaust emissions of hydrocarbons may increase or decrease, depending on such factors as engine or product design and the overall fuel properties. However, NOx emissions from conventional products and vehicles generally increase since enleanment creates conditions which increase NOx.[12] The degree of increase of NOx, however, is a complex function of engine design and other operating conditions. For sophisticated closed-loop operation, NOx emission increases can be small, but for less sophisticated open-loop engines, NOx emission increases can be dramatic. While many of the toxics 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. Again, the presence of post-combustion emissions controls such as three-way catalysts (in automobiles) can mitigate aldehyde emissions increases to a certain extent. Although there are some off-road equipment and vehicles utilizing catalytic converters today, the majority of off-road engines are not equipped with catalysts.

The emissions 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 exhaust and evaporative emissions on current engines are not fully known.

Table C presents an overview of 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.

6.0 Ethanol-Compatible Design

Scientists and engineers have learned how to make automobile and off-road engines and fuel systems compatible with ethanol-gasoline blends. For current off-road engines, the maximum amount of ethanol than can be tolerated in current designs is E10. There is very little ability in such engines to adapt to higher ethanol levels given their open-loop, factory tuned, carbureted designs. For certain automobiles, however, higher levels including E85 can be used. As noted earlier, experiences from other countries, such as Brazil, in this regard can be relevant. It is instructive to review the types of changes that have been made in certain automobiles to handle greater than E10 fuels. Table D shows the types of changes that have been made in Brazilian vehicles in order to accommodate higher ethanol blends. The reader can then understand the complexity of (a) implementing such changes across the broad spectrum of all on-road and off-

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[11] (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.

[12] Enleanment creates an increase in oxygen and nitrogen in the combustion zone.

road engines; and (b) the near impossibility of implementing such changes in the existing on-road and off-road equipment fleet.

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. Initially, a vehicle intended for higher ethanol use was designed specifically for a particular ethanol level, such as E85. Today, new technology has enabled the introduction of "flexible-fueled vehicles" (FFVs), which can burn fuel with any amount of ethanol up to E85. 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.

6.1 E0-E10

The amount and type of modifications needed increase as the ethanol concentration in the gasoline fuel increases. At levels below about 5-6% ethanol by volume, product changes generally are not needed because the ethanol concentration is too low to cause significant impacts. Fuel blends with about 5-10% ethanol by volume, however, begin to require product important changes to maintain performance, durability, and/or emissions capabilities. For example, manufacturers can increase the corrosion resistance of some parts, such as carburetors and fuel pumps, and recalibrate the engine and emission control systems, among other possible changes.

E10 adaptations also include changing the overall fuel formula. As with any fuel, proper blending and formulation are required for best performance, durability, and emissions. ASTM International has developed voluntary industry standards for gasoline and E10 to help marketers produce fuel with acceptable formulations.

6.2 E10-E85

It should be noted at the outset that ASTM has a standard for E85 which covers formulations ranging from E70 to E85.[13] However, there are no standards for mid-level blends between E10-E70. Without standards, these formulations are being made on an ad-hoc basis by users, as needed typically by splash blending denatured ethanol with some type of base gasoline. Therefore, there is no comparability between properties of these mid-level blends made by various users.

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. 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

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[13] ASTM D5798-99, Standard Specification for Fuel Ethanol for Automotive Spark-Ignition Engines.

of these tanks, they are not feasible for the tank's interior.[14] Older yachts with fiberglass tanks have a different problem. Ethanol can chemically attack some of the resins used 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.[15]

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 corrosion would be expected to dissolve the wires and eventually cause device failure.

Corrosion inhibitors have been developed to try to delay or prevent corrosion of steel components in the ethanol distribution system, but these additives cannot be relied on to protect engines and vehicles. Furthermore, a soon to be released report by the American Petroleum Institute (API) implies corrosion inhibitors may increase stress corrosion in steel.

Manufacturers make additional design changes to address emissions and performance needs.[16] 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.

The long term durability of emission control systems is a critical issue, with current U.S. federal and California emission standards requiring 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. This will lead to the type of catalyst damage seen in an Australian study using vehicles that were also sold in the U.S.[17] 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.

As noted earlier, 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

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

[15] Ibid.

[16] "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.

[17] See references to Orbital Engine Company reports referenced earlier.

system hoses, seals, and other parts of the fuel handling system. Recent studies have shown these emissions can be quite significant.[18] Automobile vehicle manufacturers (but not off-road engine manufacturers) are now using fewer permeable components in newer vehicles, so the emissions increase is more significant for older vehicles and off-highway products. Regulators expect permeation emissions will decrease over time as the on-highway fleet turns over to the newer products, but existing data are based on the use of E0-E10. Permeation rates for higher ethanol blends are largely unknown.

7.0 Conclusions

There are significant known and unknown technical issues associated with changing the U.S. conventional motor gasoline pool to accommodate higher than E10 blends. While some of these may be surmountable with additional research and the resultant use of new materials and engine/equipment designs, these can only be implemented in new equipment and with proper lead time. Important data gaps aside, with present knowledge, it is likely that there will be adverse, large-scale impacts if higher than E10 is required as motor gasoline for the existing fleet of on-road and off-road equipment, particularly the latter. Minimizing these likely adverse impacts on existing equipment and vehicles would require significant and expensive adaptation and mitigation measures.

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[18] 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.

Table A

Types of Off-Road Equipment

A. Broad Categories

- Lawn and Garden
  - Hand-Held (chainsaws, trimmers, blowers, edgers, etc.)
  - Ground-Supported (lawn mowers, rider mowers, etc.)
- Industrial Equipment (generators, forklifts, etc.)
- Snow (snowmobiles, etc.)
- Marine (outboard/PWC, inboard, stern-drive)
- Off-Road Motorcycles
- All Terrain Vehicles

B. Detailed List

2-Wheel Tractors	Other Agricultural Equipment
Aerial Lifts	Other Construction Equipment
Agricultural Mowers	Other General Industrial Equipment
Agricultural Tractors	Other Lawn & Garden Equipment
Air Compressors	Other Material Handling Equipment
Air Conditioners	Paving Equipment
Air Start Units	Personal Water Craft
All-Terrain Utility Vehicles	Plate Compactors
Asphalt Pavers	Pressure Washers
Baggage Tugs	Pumps
Balers	Rear Engine Riding Mowers
Belt Loaders	Rollers
Bobtails	Rough Terrain Forklifts
Bore/Drill Rigs	Rubber Tired Loaders
Cargo Loaders	Sailboat Auxiliary Inboard Engines
Cement and Mortar Mixers	Sailboat Auxiliary Outboard Engines
Chainsaws	Shredders
Chippers/Stump Grinders	Signal Boards
Combines	Skid Steer Loaders
Commercial Turf Equipment	Snowblowers
Concrete/Industrial Saws	Snowmobiles
Cranes	Specialty Vehicles
Crushing/Processing Equipment	Sprayers
Deicers	Surfacing Equipment
Dumpers/Tenders	Swathers
Forklifts	Sweepers/Scrubbers
Front Mowers	Tampers/Rammers
Fuel Trucks	Tillers
Generator Sets	Tractors/Loaders/Backhoes
Golfcarts	Transport Refrigeration Units
Ground Power Units	Trenchers
Hydro Power Units	Trimmers/Edgers/Brush Cutters
Lav Carts	Vessels w/Inboard Engines
Lav Trucks	Vessels w/Inboard Jet Engines
Lawn & Garden Tractors	Vessels w/Inboard/Outboard Engines
Lawn Mowers	Vessels w/Outboard Engines
Leaf Blowers/Vacuums	Water Trucks
Minibikes	Welders
Motorcycles	Wood Splitters

Table B

Diversity of Materials Used in Engine and Fuel Systems

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

Table C

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.[19] 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 driveability. 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 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 driveability 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.[20]

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[19] See API Publication 4261, June 2001

[20] See "Important News for Boat Owners," at www.ethanolrfa.org.

Table D

Adaptation of Brazilian Vehicles[21] for Use with E22 or E85+[22]

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 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.

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[21] 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.

[22] “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.

Attachment A

Author Biographical Sketch

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EXPERIENCE SUMMARY

Dr. Sahu has a Bachelors of Technology (Mechanical Engineering) degree from the Indian Institute of Technology (IIT, Kharagpur) as well as a M.S/Ph.D in Mechanical Engineering (Combustion) from the California Institute of Technology (Caltech).

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.