May 21, 2010

Federal Trade Commission
Office of the Secretary
Room H-125 (Annex M)
600 Pennsylvania Avenue, N.W.
Washington, D.C. 20580

Re: Fuel Rating Review, Matter No. R811005

Dear Sir or Madam:

The Association of International Automobile Manufacturers (AIAM) is a trade association representing fifteen (15) international automobile manufacturers which account for approximately 40 percent of the new vehicles sold in the U.S. annually.[1] We appreciate the opportunity to provide comments regarding the FTC's notice of proposed rulemaking on Automotive Fuel Ratings, Certification and Posting (75 FR 12470; March 16, 2010).

We are concerned principally with the portion of this proposal which addresses fuel pump labeling for gasoline/ethanol fuels.

AIAM believes that fuel pump labels provide an important tool for:

1. Informing consumers about the fuel being dispensed, and
2. Providing warnings when the consumer's choice of fuel could damage his vehicle (or other products fueled with gasoline).

As noted in the FTC proposal, there is much interest in the potential for mid-level ethanol blends (above 10% ethanol) due to the renewable energy requirements of the Energy Independence and Security Act of 2007. The U.S. Environmental Protection Agency (EPA) is currently considering a request for a fuel waiver from Growth Energy to allow up to 15% ethanol in unleaded gasoline (i.e., E15). EPA's decision in this matter is expected as early as this summer. AIAM has submitted comments to EPA regarding this waiver request, which are enclosed.

[1] AIAM's members include Aston Martin Lagonda, Ferrari, Honda, Hyundai, Isuzu, Kia, Mahindra, Maserati, McLaren, Mitsubishi, Nissan, Peugeot, Subaru, Suzuki, and Toyota. AIAM also represents original equipment manufacturers and other automotive-related trade associations. For further information, visit www.aiam.org.

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It is important to note that at this time the current legal limit for ethanol in gasoline is set by EPA at 10% (i.e., E10). Therefore, any gasoline/ethanol blend above E10 is legal for use only in flexible fuel vehicles (FFVs). Until this situation changes, any gasoline pump labels for mid and higher blends of ethanol should contain warnings for consumers that such fuel is "For Use in Flexible Fuel Vehicles Only; Check Owner's Manual" in bold print. Such labels should be prominently displayed on gasoline pumps.

Because of the complexities involved in this E15 waiver request, EPA is considering whether to initiate its own rulemaking on gasoline pump labeling later this year. Given the likelihood of this EPA rulemaking in the near term, we believe it would be prudent for the FTC to consult and work with EPA on a joint rulemaking to address appropriate pump labeling requirements for ethanol blended gasoline. Such a joint action would avoid duplication and possible conflicts that could arise otherwise. Such joint action would also be appropriate since EPA action is necessary before mid level gasoline/ethanol blends will be legal for sale in the marketplace.

AIAM member companies' primary concern is that consumers have the right information to make correct choices about the fuel they purchase to ensure proper vehicle operation, low emissions, and optimal fuel economy. In addition, it is particularly important for consumers to know when a fuel could damage their vehicles (or another product fueled by gasoline). Different gasoline/ethanol blends could have differing effects for different vehicles, and the impacts on other gasoline powered products, such as lawn mowers, chain saws, and motorboats, can vary even more. Consequently, pump labels for different fuels or different pump configurations may vary.

Keeping in mind that the FTC's primary concern is consumer protection, we believe the FTC (and EPA for that matter) should focus on what consumers need to know to make informed choices. The messages that need to be conveyed in the labels are important, complex and differ depending on the fuel, the vehicle/engine using that fuel (e.g., new vehicle, old vehicle, FFV, motorboat, lawn mower, chain saw, etc.) and possibly the type of pump the customer is using. Accordingly, the FTC should consider whether different labels are needed for different pumps. For instance, the label on an E85 only pump could be relatively simple ("For Use Only in Flexible Fuel Vehicles"); whereas, the label on a blender pump or an E15 only pump would have to convey more information (such as, which products the fuel can or cannot be used in; consult owner's manual, etc.). The label on an E10 only pump could say "Contains 10% ethanol; Not for Marine Use." These examples are for illustration only and are not intended as AIAM recommendations, but the point is that there is no "one-size fit" for pump labels.

AIAM is not prepared today to advise you on what the information content for such labels should be, but we stand ready to work with the FTC, EPA and other stakeholders to identify reasonable options for gasoline pump labeling for a future joint agency rulemaking. It is also worthwhile to note that, in an unrelated matter, the EPA on May 20, 2010 published a request for comments in the Federal Register (see 75 FR 26751) on a proposed Information Collection Request for a Focus Group and Internet Research Survey for Improving Fuel Economy Labeling and Content. The EPA fuel economy label has a similar purpose as gasoline pump labels, i.e., consumer protection and information. The FTC should give serious consideration to using these types of analytical methods to determine consumers' attitudes and preferences for pump labels.

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In light of the situation with the pending Growth Energy waiver request, the potential for an upcoming EPA rulemaking on pump labeling, and the related complexities associated with the potential for a variety of mid-level gasoline/ethanol blends in the marketplace, AIAM respectfully requests that the FTC defer further action on this rulemaking and instead align its efforts with EPA on a joint rulemaking on gasoline pump labeling.

If you have any questions on our comments, please contact John Cabaniss of my staff at (703) 247-2107.

Sincerely,

Michael J. Stanton
President & CEO

cc: Margo Oge, EPA
Karl Simon, EPA

Enclosure

Chairman
J. MENDEL
Honda

President
M. STANTON

July 20, 2009

Air and Radiation Docket
Docket ID No. EPA-HQ-OAR-2009-0211
U.S. Environmental Protection Agency
Mailcode: 6102T
1200 Pennsylvania Avenue, NW
Washington, DC 20460

Dear Sirs or Madam:

The Association of International Automobile Manufacturers (AIAM)[1] is pleased to provide comments in response to EPA's *Federal Register* notice (74 FR 18228; April 21, 2009) announcing receipt of a Section 211 (f) Clean Air Act waiver application to increase the allowable ethanol content of gasoline up to 15 percent and requesting comments thereon. As explained further below, AIAM takes the following positions with respect to this waiver application:

1. EPA should deny this waiver application in its entirety due to the incompleteness of the supporting technical information submitted by the waiver applicant(s). The applicant(s) failed to provide information to demonstrate that ethanol blends exceeding the currently allowed level of 10 percent (i.e., E10) up to 15 percent (E15) will not cause or contribute to a failure of an emissions control device or system over the useful life of a vehicle or engine. Such information is not yet available to substantiate the applicant's claims.

2. AIAM cannot envision scenarios whereby a dual fuel distribution system (i.e., both current gasoline would remain available widely for some vehicle/engine applications and a new E15 blend would be available for specifically identified vehicle/engine applications) could be developed that would not result in misfueling of vehicles/engines and risk of adverse environmental, safety, and consumer impacts.

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[1] The Association of International Automobile Manufacturers, Inc. (AIAM) is a trade association representing 13 international motor vehicle manufacturers who account for 40 percent of all passenger cars and light trucks sold annually in the United States. AIAM provides members with information, analysis and advocacy on a wide variety of legislative and regulatory issues impacting the auto sector. AIAM is dedicated to the promotion of free trade and to policies that enhance motor vehicle safety and the protection of the environment. For more information, visit our website at www.aiam.org.

Since the waiver applicant(s) have not provided the technical information necessary to justify EPA approval of a Section 211(f) waiver, AIAM believes the agency has no choice but to disapprove the waiver application.

In addition, as a member of the Alliance for a Safe Alternative Fuels Environment (AllSAFE), AIAM supports the comments submitted on behalf of AllSAFE.

Literature Search and Summary

To assist us in reviewing this E15 waiver request, AIAM retained an outside consultant to review the existing technical literature for studies pertaining to the impacts of the use of mid-level ethanol blends on vehicles, engines, and equipment. His report (enclosed) includes a list of the studies identified and summaries of relevant findings of these studies. This report is attached. Based on this literature search, our consultant concluded the following:

- E15 will tend to reduce exhaust emissions of total hydrocarbons/non-methane organic gases, carbon monoxide, benzene and butadiene in on-road and non-road engines.
- E15 will tend to increase exhaust emissions of nitrogen oxides and acetaldehyde in on-road and non-road engines.
- E15 will tend to raise exhaust gas temperatures in some on-road engines and in most non-road engines. This may have a negative impact on engine and catalyst durability.
- E15 will increase evaporative emissions in on-road vehicles.
- E15 will directionally worsen driveability in some on-road engines and in many non-road engines.
- E15 may cause serious safety hazards, such as inadvertent clutch engagement in non-road engines, which could lead to personal injury.
- E15 may cause premature failure of some parts in some non-road engines.
- More data is needed to understand the impact of E15, and a number of programs are being carried out or are being planned to address this need.

Lack of Technical Support Information

As noted above, the fundamental reason EPA must deny this waiver is that the applicant(s) failed to provide complete technical justification to support the waiver application. Section 211(f) of the Clean Air Act prohibits generally any new fuels or additives unless they are deemed "substantially similar" to conventional fuels; however, Section 211(f)(4) allows EPA to waive this prohibition, if the agency determines that a new fuel or additive "will not cause or contribute to a failure of any emission control device or system (over the useful life of any vehicle in which such device or system is used) to achieve compliance by the vehicle with the emission standards with respect to which it has been certified." In short, the producer of any new fuel or fuel additive (F/FA) must show that the new F/FA will not cause or contribute to the failure of any vehicle or engine to meet emission standards.

For the past thirty years, since these fuel waiver provisions have been effective, EPA has on many occasions[2] emphasized that waiver applicants must address four basic matters in their technical documentation for a waiver:

1. Vehicle/engine exhaust emissions
2. Vehicle/equipment evaporative emissions
3. Materials compatibility
4. Driveability and performance

These factors must be evaluated on a representative test fleet of sufficient size and with a variety of technologies. In addition, the testing program should include multiple test cycles per product to address test variability and must include testing to cover both short-term impacts and long-term durability impacts.[3]

For emissions, EPA requires both exhaust and evaporative emissions testing using the appropriate certification test procedures. Testing must cover all regulated vehicle and engine types for which the new F/FA could be used, including on-highway vehicles (cars, light trucks, medium and heavy trucks, motorcycles), as well as various types of regulated non-road engines, such as engines used in lawn and garden equipment, marine engines, snowmobiles, and outdoor power equipment. Testing must cover the potential for cumulative impacts that could result over prolonged use of the new F/FA (i.e., durability testing), such as those resulting from changes in combustion temperatures that could potentially lead to thermal impacts on sensors, catalytic converters, or other emissions systems components. For onboard diagnostics (OBD)-equipped vehicles, the immediate and longer term effects of a new F/FA on the OBD system should also be assessed.

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[2] See, for instance: Jim Caldwell, EPA Office of Transportation and Air Quality, presentation at the SAE Government/Industry Meeting, May 13, 2008; and/or
Karl Simon, EPA Office of Transportation and Air Quality, presentation at the American Petroleum Institute's Technology Committee meeting, June 6, 2008.

[3] See Christine Todd Whitman, Letter to Ethyl Corporation, Denying Petitions for Reconsideration of Three EPA Regulations: CAP 2000, Heavy Duty Gasoline, and OBD/IM, http://www.epa.gov/oms/standards.htm, August 23, 2001. See also AllSAFE comments on this E15 waiver consideration, Exhibit B, Supplemental Statutory Appendix.

For materials compatibility/durability, the most important factor is whether vehicle, engine, and fuel system, as well as infrastructure equipment, exposed to a new F/FA experience property changes due to prolonged exposure that could lead to deterioration or failure. The primary focus on materials compatibility is typically on shrinkage, swelling, cracking, corrosion and other physical changes in the fuel system.

For driveability and performance, testing must show that the use of the new F/FA does not result in poor driveability or performance of vehicles. Poor driveability or performance could result in impairment of components of an emission system or OBD system, could cause customer dissatisfaction with their vehicle, or could cause consumers to tamper with emission controls in an effort to improve performance.

Table 1 summarizes the information required by EPA and what was submitted by the applicant in support of this E15 waiver compared to ongoing, existing test plans for mid-level ethanol blends by the U.S. Department of Energy (DOE), the Coordinating Research Council (CRC) and AllSAFE. As demonstrated in Table 1, the data submitted by the applicant was incomplete and did not sufficiently cover all topics required by EPA. Table 1 also shows that DOE, CRC, and AllSafe in coordination with EPA have plans to test all aspects required for a waiver submittal. In many cases, the studies are under way today. Others are scheduled and still others are awaiting necessary funding; testing is expected to continue into 2010. Under the waiver submittal process, EPA has 270 days to respond to the waiver (December 1, 2009 as designated in the *Federal Register* notice of April 21, 2009). In order to make an informed decision on the waiver, the data should be complete prior to the waiver decision. Although the needed studies have been identified and interested stakeholders are moving ahead to fill the gaps in current knowledge, a complete data set will not be available in time to inform the waiver process prior to EPA's deadline.

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Table 1: Comparison of Technical Support Documents Required by EPA Versus Those Submitted by the Applicant(s) and Those In DOE and CRC/AllSAFE Test Plans

Highway Vehicles				
Item	**EPA Requirements**	**E15 Application**	**DOE Test Plan (Timing)**	**CRC/AllSAFE Test Plan (Timing)**
1.	**Exhaust Emissions**	Limited use of certification procedure	Yes (1: Catalyst Temperatures Completed May 2008 2: Selected Legacy Vehicles June 2009 3: Durability, Dec. 2009)	Yes
	a. Comparison to E0 and E10	Some	Yes	Yes
	b. Full Useful Life	No	Yes	Yes
	c. Back to Back Vehicle Pairs	No	Yes	Yes
2.	**Evaporative Emissions**	Yes	Yes (Completed Sept 2008)	Yes (Completed Sept 2008)
	a. Comparison to E0 and E10	Yes	Yes	Yes
	b. Full Useful Life	No	Yes	Yes
	c. Back to Back Vehicle Pairs	No	Yes	Yes
3.	**OBD Testing**	No	No	Yes
	a. Real World Aging	No	No	Yes
4.	**Materials Compatibility**	Yes: Significant Failures	Yes: Screening (1: Fuel System Materials Completed Dec. 2008 2: Dispenser Materials, TBD)	Yes (Fuel System Materials Completed Dec. 2008)
	a. Long Term Mileage Accumulation	No	Partial	Yes
5.	**Driveability**	Yes	Yes (Completed June 2008)	Yes (Completed June 2008)
	a. Older Vehicles	No	No	?
6.	**Representative Test Fleet**	No	No	Yes
7.	**Health Effects**	No	No	No

While industry is attempting to close the information gaps related to E15 use with plans for numerous studies, EPA is ultimately responsible for assessing whether the completed and planned test programs will provide adequate information about E15 impacts on a (statistically) representative fleet. In addition, EPA must ensure that a study is conducted that evaluates the health and environmental impacts from E15 use, and this information should be considered in determining the appropriateness of a waiver; AIAM is not aware of any health effects testing underway at this time for E15. EPA may also want to consider developing a panel of experts to review and assess all testing and whether it will be adequate, in the future, to address concerns related to E15 use.

Auto Manufacturer In-Use Compliance Liability

Under EPA regulations, if motor vehicles fail to meet emissions standards in-use within the statutory useful life period, then auto manufacturers are liable for recall and repair of the subject vehicles. AIAM is concerned that the use of mid-level ethanol blends could lead immediately to higher emissions of oxides of nitrogen (NOx) and higher evaporative emissions (due both to higher vapor loads as well as increased permeation rates). In addition, automakers are concerned that the use of mid-level ethanol blends could potentially lead to more rapid deterioration and possibly failure of emissions control components. Such emissions increases would at least reduce the head-room that manufacturers design into vehicles to ensure emission compliance in-use. If such issues are realized in the field, then they could "contribute to" the possibility of future in-use failures. In all these cases, auto manufacturers' recall liability is increased. Given the extremely stringent vehicle emissions standards in effect today, it is probable and perhaps likely that such emissions increases could cause or contribute to vehicles failing to meet emissions standards in use.

Other potential concerns that could lead to emissions increases are that:

- Permeation-related evaporative emissions may increase due to E15 impacts on the physical characteristics of materials over an extended timeframe, and
- Higher exhaust temperatures with E15 may lead to more rapid deterioration of catalytic converters or exhaust sensors.

Auto Manufacturer Warranty Liability

AIAM is concerned that the in-service fleet was not designed for ethanol blends greater than E10 (except for FFVs) and use of such blends could result in a higher occurrence of warranty-related repairs. Such cases could be exacerbated by the fact that all 1996 and newer model year light duty vehicles manufactured are equipped with onboard diagnostics (OBD) systems, which would indicate to the owner that the vehicle may be experiencing an emissions-related issue. In many cases, the OBD MIL illumination may be due solely to fuel effects and may not be readily identifiable or repairable by technicians. Without sufficient vehicle durability and performance testing, it cannot be determined whether the use of E15 will cause or contribute to higher OBD MIL illumination and resultant warranty claims.

Consumer Liability

AIAM is concerned that the pre-mature introduction of E15 without complete testing has a high risk of creating consumer problems and potentially result in consumer dissatisfaction with E15 and/or their vehicles. First, AIAM is concerned that the in-service fleet was not designed for ethanol blends greater than E10 (except for FFVs); therefore, there is a concern that legacy vehicles will not perform properly in-use when using a mid-level ethanol blend. The vast majority of in-service vehicles are no longer covered under manufacturer warranties, and repairing any in-service issues due to the use of E15 may result in increased costs to the customer. Such cases could be exacerbated by the fact that all 1996 and newer model year light duty vehicles manufactured are equipped with onboard diagnostics (OBD) systems, which would indicate to the owner that the vehicle may be experiencing an emissions-related issue. Any performance issues, driveability issues, OBD failures, or other problems associated with E15 fuel will be the responsibility of the vehicle owners to have corrected at their own expense. These problems could be particularly problematic in areas with vehicle inspection/maintenance (I/M) programs. Approximately 150 million vehicles in over 30 states are subject to I/M programs.

Second, due to the lower energy content of E15 blends, consumers will be experiencing reduced fuel economy in service. It is very important for consumers to be made aware that any reduction in fuel economy is due to the new F/FA and not the vehicle. However, inevitably manufacturers and dealers will receive a multitude of related complaints.

Third, potential increases in vehicle-related problems could damage product reputations. If certain brands, models, or types of vehicles fail to perform properly with E15 fuel, the impacted vehicles could create negative brand images for the affected manufacturers through no fault of their own. These impacts could include higher OBD MIL illuminations, higher I/M program failure rates, poor driveability or performance, poorer fuel economy, and higher warranty claims. All of these problems could lead to significant inconvenience for and dissatisfaction of consumers.

Finally, an evaluation of in-use issues, such as vehicle labeling, pump labeling, misfueling, consumer education, etc., needs to be conducted. Information on such issues is not readily available. EPA should fully consider all in-use scenarios and evaluate potential information needs to address each scenario. Use of a new fuel should require adequate lead time and a well-thought out implementation strategy in order to prevent in-field issues.

Fuel Quality and Infrastructure Considerations

AIAM member companies are particularly concerned about the effects of an E15 fuel on overall transportation fuel quality. While we expect the fuel industry to elaborate extensively on fuel quality issues, auto manufacturers are equally concerned that the proper process is followed and that adequate lead-time is provided to ensure that both legacy and future products have the proper fuels in the marketplace. The American Society for Testing & Materials (ASTM), which is supported by the auto and oil industries, has traditionally set specifications for transportation fuels. Currently there are no ASTM specifications for an E15 blend. This lack of standards raises concerns among AIAM members about what is required for producing blendstocks suitable for blending E15 fuel and ensuring adequate fuel quality.

In EPA's *Federal Register* notice of April 21, 2009, the agency asked specifically for comments on how an E15 waiver might affect other fuel regulations and the need for amendments. Again we expect the oil industry to comment extensively on this matter, but AIAM believes that EPA must fully consider the potential impacts an E15 blend could have on EPA's fuel regulations for fuel volatility, reformulated gasoline, anti-dumping requirements, gasoline detergency, and any other fuel regulation which may be affected.

It is essential for EPA to consider any potential fuel distribution infrastructure impacts which could result from the use of a new F/FA. AIAM notes that the section 211(f) requirements for EPA's evaluation of the acceptability of a fuel waiver does not explicitly include the consideration of the impacts a new F/FA could have on the production, distribution, storage, and marketing of the fuel. However, in its April 21, 2009 *Federal Register* notice, the agency requested comments on the potential impacts E15 could have on the fuel production, distribution, and marketing infrastructure. Only by collection and review of such information can there be assurance that the new F/FA will not cause or contribute to fuel leaks, vapor leaks, or other service station storage or pump system issues which could have public health and safety concerns. To our knowledge, there are no studies underway to evaluate infrastructure impacts, but such work should an important consideration in the waiver decision process.

Implications of a Partial or Conditional Waiver[4]

In its April 21, 2009 Federal Register notice, EPA requested comments on the possibility of a partial or conditional waiver of E15 blends. The concept as presented is that E15 fuel could be approved for certain applications and not others. For instance, EPA might conclude that E15 was acceptable for certain motor vehicles and not others, or for certain highway vehicles but not

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[4] Based on AIAM's preliminary legal analysis of section 211(f) of the Clean Air Act (and the legal analysis contained in AllSAFE's comments), it is not clear what, if any, authority EPA has for granting a partial or conditional fuel waiver. The underlying rationale for the abbreviated waiver process as opposed to requiring a full rulemaking under the Administrative Procedure Act (APA) for approving new fuels, was premised on the notion that such agency action could be based on a quick review of the technical factors presented in the applicant's supporting tests and other documentation and any public comment. Here, EPA is proposing a complex approach that requires more regulatory guidance more appropriately addressed as part of a rulemaking process under the APA and analogous Clean Air Act prescriptions.

for non-road engines. Such action would result in a complicated bifurcated fuel distribution system which would raise a wide range of potential policy and technical issues. A partial list of these issues includes:

- How to identify vehicles and engines capable of using E15 versus those that should not
- How to prevent misfueling
- How to accommodate dual distribution systems at fuel stations
- What are the costs of a dual distribution system
- How to educate consumers about which fuel they need and the fuel economy impacts of that fuel
- What pump labeling should be required
- What vehicle/engine labeling should be required

As noted earlier, AIAM can envision no scenarios whereby a dual fuel distribution system (i.e., both current gasoline would remain available widely for some vehicle/engine applications and a new E15 blend would be available widely for specifically identified vehicle/engine applications) that would not result in misfueling of vehicles/engines and creating risk of environmental, safety, and consumer issues. Given the complexity and diversity of these issues, AIAM believes it would be necessary for EPA to consider such matters only through a formal rulemaking under section 211(c). EPA's experience with the problems associated with the bifurcated leaded and unleaded fuels distribution system in the 1970s, 1980s, and early 1990s, is illustrative of the myriad issues that can arise due to a bifurcated system.

Conclusion

In light of the above, AIAM believes that it is clear that the waiver applicant(s) has not met the statutory and regulatory requirements necessary to support the waiver application due to a lack of information; the required information to grant a waiver, in full or partially, was incomplete, and other parties' studies will not be completed in time to inform this waiver consideration. Consequently, EPA has no choice but to deny the waiver for E15 blended gasoline at this time.

Although the current situation – a lack of adequate test data – warrants that EPA deny the waiver at this time, the waiver may be appropriate in the future, once sufficient, statistically-valid data are available. AIAM cannot support hasty implementation of E15 when the full impacts of usage are not understood and will not be understood for some time, but AIAM believes that EPA and industry have an opportunity to work together, now, to plan for future ethanol uses, including vehicle-related needs and in-field implementation strategies (labeling, pumps, education).

Sincerely,

Michael J. Stanton
President and CEO

Enclosure

cc: Margo Oge, EPA
Karl Simon, EPA

A Literature Survey of the Effects of Higher Ethanol Concentrations in On-Road and Off-Road Engines and Vehicles

Emissions, Operability and Materials Compatibility

Prepared for the

Association of International Automobile Manufacturers

by

Albert M. Hochhauser, Ph.D.

Independent Consultant

July 15, 2009

EXECUTIVE SUMMARY

Growth Energy submitted a request to EPA[1] to approve use of 15% ethanol in gasoline blends. A review was conducted of the technical literature pertaining to the use of intermediate levels of ethanol (>10%) in gasoline. Based on the review, the following conclusions about the potential use of E15[2] relative to E0 were reached:

- E15 will increase emissions of NOx and acetaldehyde, and will reduce emissions of HC, CO, benzene and butadiene in on-road and non-road engines.
- E15 will increase exhaust gas temperatures, and may negatively impact engine and catalyst durability in on-road and non-road engines.
- E15 will increase evaporative emissions.
- E15 will worsen driveability in some on-road engines and in many non-road engines.
- E15 may cause serious safety hazards and increased risk of injury in non-road engines.
- E15 may cause premature failure of parts in non-road engines.

More data are needed to be able to draw sound conclusions about the extent and magnitude of these effects. Considerable research is underway and/or being planned to address many of these issues. Therefore, it is premature to conclude that the use of E15 will not have serious adverse impacts on end-use equipment.

INTRODUCTION

On March 6, 2009, Growth Energy submitted a request to EPA to approve the use of gasoline containing 15% ethanol in the United States. EPA approval is required under Section 211 (f) (4) of the Clean Air Act before a new fuel or fuel additive can be introduced into commerce. The applicant must show that the proposed fuel composition will not “cause or contribute to the failure of any emission control device or system” to meet the applicable emission standard. The target population would include cars, gasoline fueled trucks, small engines such as used in garden equipment, and marine engines.

In past rulings, EPA has defined negative effects as

- causing emissions to increase directly
- causing emissions to increase indirectly by causing failures in control systems or system materials

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[1] A list of acronyms appears on page 21 of the report.

[2] Throughout this report, the symbol Exx refers to ethanol-gasoline blends containing xx% ethanol. For example, E15 is a mixture containing 15% by volume ethanol and 85% by volume gasoline.

- causing engines to operate poorly, thereby encouraging owners to disable emission control systems

This report describes the results of a literature survey and analysis to determine the state of existing knowledge concerning these effects. Technical literature was surveyed, as well as government reports and reports by independent organizations such as the Coordinating Research Council (CRC).

A great deal of literature has been published concerning the effects of 10% ethanol, and 85% ethanol. Since the waiver request is for an ethanol concentration of 15%, the existing literature is much less complete. This review focused on programs that tested concentrations above 10% and less than 85%.

Some programs tested ethanol concentrations of 20%. Where no problems were encountered, it is likely that 15% will also be acceptable. However, where problems were encountered with 20%, the implications for 15% are less clear. It can be argued that the Precautionary Principle[3] should apply and that 15% should not be approved. On the other hand, it can be argued that problems at 20% have no bearing on the existence or lack of problems at 15%. That decision will have to be made by EPA in its evaluation of the waiver request.

ISSUES IN THE LITERATURE

There are a number of common issues that were encountered when surveying the literature, and these are discussed below. The impact of these issues will be highlighted where relevant.

1. Existing Versus Modified Equipment – The waiver request must consider existing vehicles and equipment that were not designed and certified to use ethanol concentrations higher than 10%. There may also be issues with Flexible Fuel Vehicles that can operate on ethanol concentrations between 0% and 85%. Many current FFVs are designed to “expect” refueling with gasoline containing ethanol in one of two ranges: 0-10% or 70-85%. Refueling with gasoline containing ethanol outside these ranges may confound the calculation of proper stoichiometry and may cause an increase - temporarily - in emissions and a degradation in driveability.

   Some published studies have shown that it is possible to modify equipment to operate on higher concentrations of ethanol. While this is important for future designs, it is not relevant to the current question which must focus on existing vehicles and equipment.

2. Fuels Blending – Most of the studies cited in the literature tested fuels that were splash blended, and this introduces some uncertainty into the results and conclusions. Well designed fuel studies control levels of all other chemical and physical properties when comparing fuels. For instance, since ethanol generally contributes to an increase in the RVP (Reid Vapor Pressure) of the blend, it is necessary to adjust the RVP of the blended fuel. Otherwise, it is not possible to determine whether the effect was due to the addition of

[3] One definition of the Precautionary Principle states that it is the responsibility of an activity proponent to establish that the proposed activity will not (or is very unlikely to) result in significant harm. (www.wikipedia.org)

ethanol or to the change in RVP.

Similarly, in comparing splash blended fuels, emissions effects may be due to the addition of ethanol or to the dilution of other properties such as sulfur. A negative effect of ethanol that has been reported is an increase in exhaust NOx (oxides of nitrogen) emissions. There is also evidence that reducing aromatics and/or sulfur will reduce exhaust NOx emissions. If ethanol is splash blended, the impact on exhaust emissions is difficult to assign. If no effect was found, it could be because the aromatics and sulfur effects cancelled out the ethanol effect.

Another example involves material compatibility tests. If ethanol is splash blended, then other properties, such as aromatics change. Aromatics are known to affect the swelling of elastomers. When two fuels are compared which have different levels of ethanol and different levels of aromatics, it may not be possible to determine the cause of the response measured.

The issue of fuel properties is important because most commercial fuels are not made by splash blending ethanol. Special blends are made to be combined with the appropriate amount of ethanol at the terminal before delivery to service stations. Properties of the base blend are adjusted so that the final blend including ethanol has the appropriate properties specified by law and by standard setting organizations such as ASTM. The base blend may be called a BOB (blendstock for oxygen blending) or RBOB (reformulated blendstock for oxygen blending).

In some cases, technical judgment may be used to clearly identify an effect, while in others the uncertainty may remain. These will be discussed in more detail below.

3. Proper Fuels for Comparisons – When testing fuels and drawing technical conclusions, it is important to specify the proper comparison to be made. The question is whether E15 should be compared to E10 or to E0. The Clean Air Act defines the impact of a new fuel by comparing it to the fuel used in 1974, which did not have any oxygenate. Many of the studies, and the waiver request as well, compared E15 and E10. The syllogistic argument is made that if E10 is no worse than E0, and if E15 is no worse than E10, then E15 must be no worse than E0. This argument is logically sound, but ignores the uncertainty introduced by experiment variability. If two fuels have properties that are close to each other, then it is difficult to design a test with enough statistical power to be certain of finding an effect if it exists. Therefore, the best approach should be to compare E0 and E15 directly.

4. Emissions Testing and Measurements – Standard tests exist for measuring emissions. For instance, in the U.S., the standard test is defined by EPA and consists of simulated driving on a dynamometer. Some programs in the literature used steady state testing, which makes the results less applicable to the issue at hand. Some programs change design parameters and operating conditions to optimize operation on different fuels. While this approach can generate useful information for future applications, it may not be relevant when considering use of ethanol in existing vehicles and equipment which cannot be modified to accommodate new fuels.

   Hydrocarbon exhaust emissions are typically measured using a Flame Ionization Detector (FID). When the fuel contains high concentrations of ethanol, the exhaust contains ethanol as well. Emissions that may contain high concentrations of ethanol should measure the property NMOG (non-methane organic gases). NMOG is also the appropriate measure for EPA emissions certification. This measurement involves measuring the ethanol content of the exhaust and correcting the FID measurements. Many of the reports in the literature did not use this approach, so that the emissions measurements may have some uncertainty. This might lower the benefits claimed for ethanol in reducing hydrocarbon emissions. It is expected that for E10 and E20, this effect will be small. For example, in the CRC E-67 program [1], with E10, ethanol represented about 3% of the NMOG emissions.

The standard equations for calculating fuel economy from an emissions test are not applicable for fuels with ethanol, because they contain a factor to correct all fuels to a common volumetric energy content. A method using carbon balance technique without an energy correction should be used.[2] It is not clear in the literature whether this approach was always followed.

5. Test and Equipment Location - The location of the test may be an important factor in evaluating the literature. Some countries have different emission standards leading to different vehicle and engine designs and different control equipment. Countries that have significant numbers of automobiles with carburetors may not be representative of the fleet in the U.S. The same may be true of materials used in engines. In the U.S., automotive materials have been compatible with E10 for over 30 years; equipment in other countries may exhibit compatibility problems. By the same token, experience from Brazil, where high levels of ethanol have been mandated for many years may not be relevant for the U.S.

SURVEY OF TECHNICAL LITERATURE

Methodology

A number of technical resources were used to locate published literature. The database maintained by the Society of Automotive Engineers – Global Mobility Database - is an extremely useful tool that can be searched easily. A number of references were cited in the waiver request, and a number of independent literature surveys have been carried out.

The literature is presented chronologically by end-use – on-road and non-road. Within each end-use application, it is organized according to the effects measured – emissions, operability and materials compatibility. Operability refers to proper and expected operation. For cars, this would mean that a car starts promptly and drives with no hesitation, misfire, stalling, etc. Materials generally refers to the impact of fuel properties on the integrity of materials such as rubbers, plastics and metals. Metals should not rust, plastics should not crack and rubbers should maintain their elasticity, strength and shape.

Two groups of programs are worth mentioning. One is a series of projects carried out by Orbital Engine Company in Australia, when that country was considering the use of E20.. The second group is a series of programs carried out by the Minnesota Center for Automotive Research (MCAR) at the Minnesota State University. Both organizations ran experimental programs, as well as literature searches. They will be discussed below. These programs are very relevant to the questions at hand because they were designed to answer specific questions about ethanol use. By contrast, some of the published technical literature may not be directly applicable because the research was not targeted at E15 use in existing equipment.

Publications dated later than 1994 were included in this report. It was felt that this time frame represents the vast majority of vehicles and engines in use today. A full bibliography of references is included at the end.

<u>Summary reports and surveys</u>:

- NREL (National Renewable Energy Laboratory) [3] wrote a report evaluating issues associated with use of higher ethanol blends, and included a complete literature survey. They concluded that there were no likely compatibility issues and that catalysts were probably unaffected.
- Orbital Engine Company [4] studied the state of knowledge of ethanol use in non-automotive engines for Environment Australia. They concluded that use of up to 10% ethanol was probably acceptable, but there was little if any information on blends containing more than 10% ethanol. Use of ethanol containing blends in aircraft engines was highlighted as a special concern.
- The Swedish Emission Research Program financed the Stockholm Study [5] to evaluate the possibility of increasing the ethanol content in Sweden from 5% to some higher value. That study reached the following conclusions:
    - Blends up to 15% will not have a significant effect on engine or vehicle performance.
    - No significant differences in regulated emissions can be seen up to 10-15% ethanol.
    - There are some increases in unregulated emissions, such as aldehydes.
    - Blends with 20% ethanol should be avoided until more data are collected.
    - For 15%, more data should be collected on cold weather starting, and health/environmental impacts.

  The conclusions, especially concerning emissions, are somewhat surprising. They did not reference the extensive U.S. Auto/Oil Air Quality Improvement Research Program [6], which showed that ethanol up to 10% has a statistically significant effect on exhaust emissions of HC (hydrocarbons), CO (carbon monoxide), NOx and aldehydes. It also concluded that alcohols and ethers had similar effects that were a function of their oxygen content.
- Waytulonis et al. [7] published results of a literature search for effects of E20 in small non-road engines. The report contains a useful summary of the issues involved in using 20% alcohol blends. The authors analyzed the available information and concluded that many gaps existed, and pointed to studies being carried out at MCAR, which have since been published and are cited below.

On-Road applications

Emissions

1. Guerreri et al. [8] tested six in-use vehicles (1990-92 model years) with ten fuels (E0, E10, E12, E14, E17, E20, E25, E30, E35 and E40) prepared by splash blending into a base gasoline. Emissions were measured as OMHCE (Organic Material Hydrocarbon Equivalent). OMHCE is similar to NMOG except for the inclusion of methane, and that the oxygen portion of ethanol is excluded in OMHCE. Over the entire range of concentrations, emissions of OMHCE, THC (total hydrocarbons) and CO decreased as ethanol concentrations increased. Similarly, emissions of NOx and acetaldehyde increased over the range of concentrations. All trends were statistically significant (95% CL). The authors conjectured that all these effects could be explained by changes in stoichiometry. At high ethanol concentrations, the closed-loop A/F control on the vehicle may not have been able to adjust fully, while at low levels, the adjustment may not have been perfect. Fuel economy was also reported and varied with energy content of the fuels.

2. Kremer et al. [9] tested four Brazilian cars on alcohols (22% in gasoline) made from sugar cane, corn, natural gas and coal. The ethanol content of the non-sugar based alcohols varied from 53% to 90% (corn). Higher molecular weight alcohols made up the difference. The report concluded that corn and sugar alcohols had similar performance and that the other alcohols increase CO emissions and had worse corrosion of metal parts. This research has little relevance to the U.S. situation because of the strict standards regulating ethanol content of fuel grade ethanol.

3. Barbosa deSa and Marins [10] tested three Brazilian vehicles with two fuels (E22, E26). One vehicle was carbureted, one had single point injection, and one had multipoint injection. Comparing E22 and E26, CO emissions were lower in one vehicle and NOx emissions were higher in one vehicle. The relevance of this study for the U.S. situation is uncertain because of the high ethanol contents and because Brazilian cars are specially designed for high ethanol content.

4. Hsieh et al. [11] tested a 1.6 liter MPFI (multi-point fuel injection) 4 cylinder engine at steady state conditions. Emissions of HC, CO and NOx depended on air-fuel ratio. When ethanol addition caused the engine to run leaner, HC and CO emissions were reduced. NOx emissions varied with equivalence ratio and went through a maximum at an equivalence ratio of about 1.

5. He et al. [12] tested a MPFI closed loop engine at two steady state conditions with three fuels (E0 and splash blended E10 and E30). The ethanol fuels had lower emissions of HC, CO and NOx under most load conditions. At full load, CO emissions for E30 were higher and NOx emissions for E10 were higher. The authors did not attempt to explain the unusual results, and they did not discuss statistical significance. Ethanol and acetaldehyde emissions were higher with the ethanol fuels.

6. Orbital Engine [13] tested five new vehicles and four older vehicles from the Australian market. Comparing splash blended E20 and E0 for the new vehicles, exhaust emissions of THC and CO were reduced (~30%) and exhaust NOx emissions increased (48%).

Acetaldehyde emissions were higher and benzene emissions were lower. In the older vehicles, HC and CO emissions were reduced (4% and 70%, respectively). NOx emissions increased for the vehicles with open loop control and decreased for the vehicle with closed loop control (average increase of 9%). There was considerable variability among the vehicles in the size of the emissions effect. Acetaldehyde emissions were higher, while emissions of benzene and 1,3 butadiene were lower (20% and 15%, respectively). Exhaust gas temperatures were higher with E20 in five of the nine vehicles, including some with closed loop control. This indicates that even with closed loop control, there can be some shift in stoichiometry. The increase in exhaust gas temperatures may have negative consequences for long term durability of the catalysts and other components of the emissions control system. See below for a description of Orbital's long term studies. [14]

There was an increase in evaporative emissions with E20, although it is not possible to ascribe the difference to ethanol since RVP likely changed as well.

7. Kaneko et al. [15] measured running loss emissions in four Japanese cars with different design features, five fuels – E0 at two levels of RVP, E3 at two levels of RVP, and E10. They showed that vehicle design parameters such as canister capacity, canister purge rate, and fuel heating are important. They also showed that even though RVP of different fuels may be matched, vapor pressure at temperatures above 100ºF may be higher for fuels with ethanol than without ethanol. This implies that even if fuels are volatility matched, there may still be a small effect of ethanol content on evaporative and running loss emissions.

8. Akasaka [16] reported on tests in nine Japanese vehicles – three passenger cars (0-5 years age), one commercial truck (10 years old), two Kei cars (minivans or mini trucks, 0-5 years old) and three motorcycles 0-10 years old). Seven fuels were tested – a base gasoline, five splash blends (E1, E3, E5, E7, E10), and an RVP adjusted blend (E5). With increasing ethanol content, exhaust emissions of CO generally went down, exhaust NOx and aldehydes generally increased, and exhaust HC were mixed for the cars, and went down for the motorcycles. Evaporative emissions were tested in two cars, and increased with higher ethanol content, but this could also be the results of increased RVP. The RVP adjusted fuel had emissions that were a little higher than the E0 fuel in one car, but the same in the second car.

9. Maheshwari et al. [17] studied splash blended E5 and E10 in Indian cars and two wheelers. Generally emissions of HC and CO decreased and emissions of NOx increased. They did not discuss the statistical analysis of these conclusions. The relevance of this study for the U.S. is uncertain because of the low ethanol concentrations, and the different equipment.

10. Orbital Engine [14] accumulated 80,000 km in five pairs of new Australian vehicles. One vehicle in each pair used E0 and one used splash blended E20. Two of the vehicles exhibited more deterioration of emissions on E20 than on E0. Orbital attributed this result to higher exhaust temperatures and greater catalyst degradation. The two vehicles did not operate under closed loop control under all driving conditions. At 80,000 km, the fleet average emissions were higher for E20 than for E0 for all three exhaust components. No effect of ethanol on deterioration of toxics emissions was seen.

11. Subramanian et al. [18] tested four Indian scooters with two-stroke engines with three fuels (E0 and splash blended E5, E10). Tests were conducted at 1,000 km, 10,000 km and 20,000 km. HC and CO emissions were reduced by large amounts with the addition of ethanol, except at low mileage. At 1,000 km, HC and CO emissions increased when ethanol was added. The explanation for this effect was unclear. NOx emissions were not reported. Acetaldehyde emissions also increased with higher ethanol levels.

    One four-stroke motorcycle was tested and emissions of HC and CO also were reduced when ethanol was added.

12. Ning et al. [19] tested two four-stroke motorcycles and one two-stroke motorcycle commonly used in China. E0 and splash blended E10 were compared after accumulating 16,000 km. Emissions of HC and CO went down significantly while NOx emissions were somewhat variable.

13. CRC carried out a program to measure emissions from 15 vehicles (2001-2003 model years) as a function of volatility and ethanol content up to 10%[1]. While the results are not directly relevant to the question of E15, this is one of the few published studies that controlled fuel properties in an orthogonal design, and which allowed statistical inferences to be drawn with certainty. There were a number of interactions among fuel properties, but generally, increasing ethanol content tended to reduce CO and NMHC (non-methane hydrocarbons) emissions and to increase NOx emissions.

14. Shockey et al. [20] measured emissions from four 2007 cars on E0 and splash blended E20 or E30. The results were scattered. THC emissions went up in two vehicles and down in two. CO emissions went up in one vehicle, down in two and were the same in one. NOx emissions were up in one vehicle, down in two and were the same in one. No statistical analysis was presented.

15. Wallner and Miers [21] tested a 2.2-liter direct injection gasoline engine with E0 and four splash blended ethanol fuels (E10, E20, E50, E85). Testing was done at various steady state conditions. Under these controlled conditions, NOx and HC emissions generally decreased as ethanol concentrations increased. The authors recognized that the NOx effects could also be explained by the fact that aromatics were also decreasing as ethanol increased, and that aromatics are known to contribute to higher flame temperatures and higher engine-out NOx emissions. Not mentioned in the paper is that HC emissions, when measured by a FID, would also tend to decrease because ethanol is not fully detected by an FID. Better measures such as OMHCE or NMOG should be employed, especially at higher ethanol concentrations.

16. Gogos et al. [22] tested a 1.3-liter, four-cylinder engine from Greece with E0 and three splash blended fuels (E10, E20, E50) under steady state conditions. The engine was removed from a car and had accumulated 170,000 km. Adding higher levels of ethanol reduced HC and CO and increased NOx emissions. These results can be explained by the fact that the engine was running rich with E0 and adding ethanol leaned out the mixture.

17. Kumar et al. [23] tested a single-cylinder automotive engine manufactured by AVL with E0 and three splash blended fuels (E10, E30, E70) in an optimized and non-optimized condition. In both configurations, as ethanol content increased, brake specific CO

emissions decreased, NOx emissions increased, and HC emissions did not change. Optimization consisted of adjusting spark advance and injection duration. They did not report stoichiometry for any of the cases.

18. Lin and Liu [24] tested a 125-cc, carbureted four-stroke motorcycle in Taiwan with E0 and five splash blended fuels (E3, E10, E20, E30, E40). Three different carburetor jets were tested. In general, for a given set of jets, as ethanol was added, CO and HC decreased and NOx increased.

19. NREL [25] carried out a study to measure emissions from 16 late model vehicles with four fuels (E0 and splash blended E10, E15, E20). The report concluded that NMHC and CO decreased with increasing ethanol, and that NOx and NMOG showed no significant change. The statistical analysis was straightforward and the confidence limits were fairly broad, suggesting that there could have been other effects that were not possible to determine. Emissions of ethanol, formaldehyde and acetaldehyde increased with increasing ethanol.
    The study also measured catalyst temperatures, a good indicator of potential long term emissions changes. Nine of the cars operated under closed loop control of air/fuel ratio under all operating conditions. These cars had no change in temperature with ethanol content. At wide open throttle, seven cars ran leaner (but still rich) with E20 than with E0. For these vehicles, catalyst temperatures at wide-open throttle averaged 10ºC higher with E10, 24ºC higher with E15 and 31ºC higher with E20.

20. Shanmugam et al. [26] tested a number of Indian cars meeting Euro3 standards with E0 and splash blended E10. While not directly relevant to the E15 question, they showed that at wide open throttle, there was an effect of ethanol on air-fuel ratio and through that change, an effect on emissions of CO, HC and NOx. There was little if any effect on emissions while the vehicles were under closed loop control of stoichiometry.

21. Muralidharan et al. [27] measured PM (particulate matter) emissions in a 97-cc, four-stroke motorcycle meeting Euro2 standards with five fuels (E0 and splash blended E5, E10, E20, E30). PM number and mass distributions were measured using the Indian driving cycle and under steady state conditions using an ELPI (Electrical Low Pressure Impactor) instrument. Under transient conditions, increasing ethanol concentration reduced the PM number concentration. This was attributed to both the presence of ethanol and the reduction in sulfur concentrations. The concentration of nanoparticles (0.028-0.94 micron) increased with higher ethanol levels. Under steady state conditions, there was no trend in PM emissions.

22. CRC [28] carried out a number of projects to measure the contribution of ethanol to evaporative emissions as a result of permeation of fuel through fuel system materials such as elastomers. They determined that the presence of ethanol increases permeation emissions significantly from light duty vehicles in the U.S. The original testing was carried out with E6, but subsequent testing showed that E10 and E20 did not have higher permeation emissions than E6. The importance of these results depends on the comparison made for the purpose of considering the waiver request. If E15 is compared to E10, then there is no impact. If E15 is compared to E0, then the impact can be considerable.

23. CRC [29] carried out a project to measure emissions at various levels of RVP and oxygenate in 15 vehicles. An E20 fuel was included in the program. Regression analysis showed that higher ethanol content reduced exhaust emissions of THC and CO and increased emissions of NOx. E20 reduced THC by 15%, reduced CO by 20% and increased NOx by 18%. While composition and RVP levels were tightly controlled, other volatility parameters such as T50 could not be controlled because of the high ethanol content. The authors pointed this out in their analysis.

24. CRC has completed the first phase of a two phase study to evaluate catalyst durability of mid-level ethanol blends. [30] Twenty-five vehicles manufactured since 1999 were evaluated over a severe wide open throttle driving cycle with four test fuels (E0, E10, E15, E20). Thirteen of the vehicles did not adjust the stoichiometry during open loop operation when fuels were changed. Eight vehicles did adjust the stoichiometry, and four vehicles gave unclear results. The implications of these results are that some vehicles may have higher exhaust gas temperatures and therefore impaired emissions as a result of long term use of E15 due to increased deterioration to catalytic converters.

    The second phase of the study will conduct long term tests of ten of the vehicles from Phase 1 that did not adjust stoichiometry during wide open throttle operation.

Operability

1. Bonnema et al. [31] tested 15 U.S. cars (1985-1998 model years) on E10 and E30 for one year and reported no driveability problems with either fuel. They reported that it required about 100 miles of driving for the vehicles to “learn” to operate on the new fuel.

2. Barbosa deSa and Marins [10] tested three Brazilian vehicles with two fuels (E22, E26). One vehicle was carbureted, one had single-point injection, and one had multi-point injection. Comparing E22 and E26, one vehicle had worse cold start performance and minor increases (3%) in acceleration times. Fuel consumption was also higher with the 26% ethanol fuel. The relevance of this study for the U.S. situation is uncertain because of the high ethanol contents and because Brazilian cars are specially designed for high ethanol content.

3. Orbital Engine [13] tested five new vehicles (2001 model year) and four older vehicles (1985-1993 model years) from the Australian market with E0 and splash blended E20. Driveability was assessed at ambient conditions (~25ºC), at hot temperatures (40ºC) and at cold temperatures (-10ºC). Differences between the fuels were judged to be noticeable to the average driver in the following cases. Two of the new vehicles had significantly worse starting performance on E20 at the cold condition. In the older vehicles hot driveability was significantly worse with E20, and would be noticeable by the average driver. Cold driveability was also significantly worse with E20 and was judged noticeable by the average driver.

4. Maheshwari et al. [17] studied splash blended E5 and E10 in Indian cars and two wheelers. No degradation in performance was seen going from 5% to 10% ethanol between 5ºC and 45ºC, except for a marginal increase in acceleration times. This is consistent with a lower

energy content. Four scooters and four passenger cars accumulated up to 40,000 km, and wear and deposit ratings were similar for E5 and E10. The authors speculated that higher doses of antioxidant and corrosion inhibitors would be needed to meet product quality specifications with higher levels of ethanol.

5. Akasaka [16] reported on tests in five Japanese vehicles – three passenger cars (0-5 years old), one commercial truck (10 years old), and two Kei cars (minivans or mini trucks, 0-5 years old). Six fuels were tested – a base gasoline and five splash blends (E1, E3, E5, E7, E10). The high ethanol fuels (E7, E10) exhibited hesitation in one of the carbureted cars. This could have been the result of higher volatility, not necessarily the ethanol itself.

6. Subramanian et al. [18] tested four Indian scooters with two-stroke engines with three fuels (E0 and splash blended E5, E10). Engine components were rated for cleanliness and wear after 20,000 km. Generally, merit ratings of E5 were better than E0. Piston cleanliness was worse for E10, but the authors felt that this could be solved by higher concentrations of antioxidants.

7. Ning et al. [19] tested two four-stroke motorcycles and one two-stroke motorcycle commonly used in China. E0 and splash blended E10 were compared after accumulating 16,000 km. With the E10 fuel, the top speed was lower, sediment was higher in one of the 4 stroke motorcycles and some piston scrape was evident. None of these problems were described as serious.

8. Cracknell and Stark [32] modeled the kinetics of lubricant oxidation and suggested that ethanol in the fuel has a positive effect on lubricant oxidative stability, but that the effect is small because ethanol has a low solubility in engine oil.

9. Kapus et al. [33] studied ethanol fuels (E0, E85, E100) in a direct injection, single-cylinder, turbocharged automotive engine. While the work is not directly relevant to the use of E15, the authors point out some of the advantages of using ethanol, such as high octane and high latent heat of evaporation. Challenges include low energy content, hard starting, cylinder wall film formation leading to excess wear, and oil dilution.

10. Taniguchi et al. [34] tested a number of ethanol concentrations in a direct injection V6 engine. Comparing E0 and E20, they found that the injector tips had lower temperatures with E20, presumably because of ethanol's high latent heat of vaporization. In a severe test, E20 had lower injector tip deposits than E0.

11. Kittelson et al. [35] compared E0 and E20 in 40 pairs of vehicles in customer driving situations for one year. The fleet consisted of seven pairs of cars and 33 pairs of trucks and vans. Each vehicle stayed on one fuel for the entire length of the test. The two fuels were not blended to match properties, and the E20 used a different base fuel than the E0. Driveability Index (DI) values were reported and the E20 had lower DI than the E0 throughout the year. This makes any comparison of driveability on the two fuels suspect, since the E20 would be expected to perform better than E0. Since the E20 was splash blended, the RVP was significantly higher than E0.

    Drivers filled out forms daily, and trained raters conducted tests four times over the course of the year. The only differences that were statistically significant were observed by lay drivers in the spring and fall, when E20 had worse driveability than E0. Trained raters did not perceive statistically significant differences. No data were shown for hot fuel handling. The analysis did not take into account the major differences in the two fuels which could either cause differences in performance or mask differences that might have occurred.

12. CRC [36] studied hot fuel handling in 27 vehicles with four fuels (E0, E5, E10, E20) blended to statistically determined volatility properties. Very few driveability demerits were measured, even under conditions that would be expected to result in hot fuel handling problems. The CRC committee could not fully explain the lack of response. It is possible that fuel flushing and handling procedures could have contributed to the lack of response, but no firm conclusions were drawn in the report. Therefore, no conclusions about fuel performance can be drawn from this study.

13. Boons et al. [37] tested lubricant performance with two ethanol fuels (E10 and E85). They were concerned that higher ethanol levels might lead to more water in the oil and to problems with rust and wear. In a severe test with four 2007 model year Dodge Dakotas and three engine oils, no problems were found that were attributed to the high ethanol content.

14. NREL [25] carried out a study to measure emissions from 16 late model vehicles with E0 and three splash blended fuels (E10, E15, E20). Limited operability evaluations were made, but no problems were uncovered.

15. CRC [38] conducted a driveability evaluation of six conventional vehicles (1981-2008 model years) with E0, E15 and E20 at cool ambient temperatures (20ºF-40ºF). The E15 and E20 results were combined when it was determined that there was no difference. Regression analysis showed that the driveability of E15/E20 was worse than E0 (marginally significant, p=0.94). This program is important because the fuels were blended to control volatility, so that it was possible to determine the effect of ethanol independent of the impact of volatility.

Materials

1. Orbital [39] tested materials taken from three high volume Australian vehicles. Polymeric materials were tested with E0 and splash blended E20, while metallic samples were tested with E20 only. The ethanol fuels had 1% corrosive water, (defined in SAE J1748). There were many instances of corrosion and tarnishing of metal parts including fuel pump casings and internals, fuel injectors, fuel tank metal and PCV valve. Orbital concluded these changes are cause for concern.

   Some polymeric materials were found to have significant changes with E20 compared to E0. These included fuel sender float, hoses, fuel regulator diaphragm, cork gaskets, etc. The changes that were seen were considered unacceptable because they could lead to fuel leaks.

   See Appendix 1 for a discussion of the composition of fuels used for materials testing.

2. Orbital engine [14] accumulated 80,000 km in 5 pairs of new Australian vehicles. One vehicle in each pair used E0 and one used splash blended E20. No major differences were

seen in wear, deposits or other factors related to mileage accumulation. E20 had slightly higher levels of wear and deposits, but these were judged to be not important. The authors felt, however, that the driving cycle was not particularly severe.

3. Nihalani et al. [40] studied the impact of gasoline-ethanol blends on polymeric materials commonly used in carburetors in Indian two wheelers and Indian fuel dispensing equipment. Three levels of ethanol (E0 and splash blended E5, E10) and two levels of aromatics (15.8%, 37.9%) were tested. Acrylonitrile Butadiene Rubber (NBR) had poor resistance to swelling in ethanol blends, and is not recommended with ethanol levels above 5% if aromatic concentrations are above 20%; and is not recommended for 10% ethanol for all aromatic levels. Conventional rubber used in the tips of carburetor float pins also had poor performance and is not recommended. The relevance of this study to the U.S. situation is uncertain because it is not known whether these materials are commonly used in U.S. applications.

4. Akasaka [16] reported on tests with five fuels – a base gasoline and four splash blends (E1, E3, E5, E10). Aluminum and aluminum/zinc samples were immersed in test blends for 720 hours at 100ºC, and developed serious corrosion. Six types of rubber and three types of plastic were immersed in fuel blends for 720 hours at 70ºC. Changes were observed as ethanol concentrations increased: the rubber hardness and tensile strength decreased, and the volume increased; and the plastics yield stress and modulus of tensile elasticity dropped and the volume increased. Details of the tests and results are available from the Japanese Agency for Natural Resources and Energy (in Japanese).

5. Orbital [41] reported on a study comparing E0, splash blended E5, and splash blended E10 in 16 cars ranging from 1984 to 2000 model years. The choices were designed to cover a large part of the Australian driving population and included five fuel-injected models and 11 carbureted models. Pre-1986 cars were not tested on E10. Orbital concluded that the fuel injected vehicles were suitable for use with E5, but had some material and durability issues with E10. The carbureted vehicles had a number of problems with E5, and Orbital concluded that these vehicles are not compatible with ethanol use. The relevance of this study to the U.S. situation is uncertain. It might be argued that since a large portion of the Australian population is not suitable for even E5, then it is not surprising that E10 had problems, and that this study should not be extrapolated to U.S. conditions when considering E15. On the other hand, it can be argued that the Australian results point out potential problems and that many of the same materials and catalyst formulations have been used in the U.S. fleet.

6. Jones et al. [42] compared the effects of splash blended E10 and E20 on 19 metals commonly used in automotive fuel systems. Metals used in FFVs were excluded from this effort because they assumed that these metals would not be affected by E20 if they had already been developed for E85. Testing was carried out according to SAE J1747 ("Recommended Methods for Conducting Corrosion Tests in Gasoline/Methanol Fuel Mixtures"). The E0 is a 50/50 mixture of toluene and iso-octane. According to SAE J1681, the ethanol was mixed with small amounts of water, sodium chloride, sulfuric acid and glacial acetic acid, and is called "aggressive ethanol". One material showed discoloration with E0, eleven showed discoloration with E10 and fourteen showed discoloration with E20.

Most of the samples showed greater discoloration with E20 than with E10. One metal, Zamak 5 had unacceptable levels of corrosion with both E10 and E20. This metal is used in some carburetors, and is sometimes plated with a more stable metal.

The authors noted that Orbital reported finding more problems with metal corrosion with E20. One possible reason is differences in the composition of the water phase between the two studies. Another is that Orbital compared E20 with E0, while Jones et al. compared E20 with E10. (See Appendix 1)

7. Jones et al. [43] studied the impact of ethanol on eight elastomers commonly used in automotive fuel systems, but not in FFVs. They used standard ASTM and SAE test methods for evaluating the impact of fuels on these elastomers. On a number of elastomers, the presence of ethanol caused different changes than E0, but the authors found that splash blended E10 and E20 were similar. The authors discussed the somewhat different results obtained by Orbital [13, 44] and concluded that there were two possible explanations. One possible reason is differences in the composition of the water phase between the two studies. Another is that Orbital compared E20 with E0, while Jones et al. compared E20 with E0. (See Appendix 1)

8. Jones at al. [45] compared the effects of splash blended E10 and E20 on eight plastics commonly used in automotive fuel systems. They did not include plastics that have been in use in FFVs, since these would likely not cause problems with E20. PVC (polyvinyl chloride flexible version), PUR (polyurethane 55D-90Adurameter Hardness), and PBT (polybutylene terephthalate) performed significantly worse in E10 and E20 than in E0. However, no fuel system components could be located that were fabricated with PUR or PVC. Based on this, it is not clear why these materials were tested. The authors discussed the somewhat different results obtained by Orbital [13, 44] and concluded that there were two possible explanations One possible reason is differences in the composition of the water phase between the two studies. Another is that Orbital compared E20 with E0, while Jones et al. compared E20 with E0. (See Appendix 1)

9. Hanson et al. [46] tested eight fuel pumps and three sending units with three fuels (E0 and splash blended E10, E20) using 30 day soak tests derived from SAE J1537. All of the pumps passed the test. One had a significant flow change with E10. All of the pumps became discolored, but the authors did not view this as a problem. None of the sending units had any significant problems. One possible problem with this test is that the ethanol did not contain any elemental sulfur, which has been shown to cause severe corrosion in some sending units. A better test would have been to include a small amount of elemental sulfur in the ethanol.

10. Thomas [47] tested a number of fluoroelastomers in six fuels (E0, E100, and splash blended E25, E50, E85). Generally performance in softening, swelling and strength tests were best for the pure fuels (E0 and E100), and worse for blends such as E10 and E25. Elastomers with higher levels of fluorine had better performance. Thomas did not discuss the relevance of these results for operation in current automobiles.

Summary of On-Road Effects

Most of the literature supports the conclusion that blending gasoline with ethanol reduces exhaust emissions of THC and CO and increases exhaust emissions of NOx and acetaldehyde. While there is not a great deal of data collected using E15, it is likely that the same effects will hold. The newest vehicles, which maintain closed-loop control of stoichiometry under all conditions, might have smaller or even zero impacts. However, most cars on the road today in the U.S. do not fall into this category.

If volatility is controlled, ethanol will not increase the volatility controlled portion of evaporative emissions, but will increase the permeation portion. In this case, the evidence suggests that E15 would be no worse than E10.

E15 will increase the emissions of aldehydes especially acetaldehyde. Other toxics, such as benzene and butadiene, should be reduced proportionally as THC is reduced.

Some data suggest that E15 use will result in higher exhaust gas temperatures, and that long term catalyst durability could be negatively impacted.

There is limited operability data, and much of it is of questionable value. The CRC program [38] found driveability differences that were marginally statistically significant. Orbital [13] found some differences, but the relevance to the U.S. fleet is not clear. Other studies had fuel design that did not separate variables [35] or used test designs with limited statistical power [25] and no definitive conclusions can be made concerning operability.

The data for ethanol's impact on materials are conflicting. MCAR [42, 43, 45, 46] programs on E20 tended to show little or no effects. Orbital's programs [13, 39] showed serious effects with E20. The relevance of Orbital data to the U.S. fleet should be evaluated carefully. There were also differences in the way that the fuels were blended for testing (see Appendix 1).

Off-Road Applications

Emissions

1. Bresenham and Reisel [48] studied emissions from three 1994 model year small (12.5 hp) engines using SAE and EPA procedures. A series of splash blends were made starting with a commercial RBOB (E0, E10, E25, and E50). As the ethanol concentration increased, HC and CO emissions decreased, and NOx emissions increased. The engines were running rich with E0, and increasing oxygen content leaned out the stoichiometry. The emissions results were fully consistent with the observed stoichiometries. Since regulations for these engines are stated in terms of HC+NOx, from a regulatory perspective, the regulated measurements were not affected by the changes in stoichiometry.
2. Martinez and Ganji [49] tested a single cylinder utility engine (2.5 hp) with five fuels (E0, E100 and splash blended E10, E20, E40). Ignition timing and stoichiometry were adjusted for each fuel for the steady state tests. At the same equivalence ratio, there was no clear trend between ethanol content and CO emissions. E100 had the lowest CO emissions, followed by E0 and then the other ethanol blends. This suggests that equivalence ratio explains most of the effect of ethanol on CO emissions. Emissions of HC+NOx were shown,

and generally, higher ethanol levels reduced HC+NOx. The reasons for this were not explored. This study has limited relevance because the engine was adjusted for each fuel. However, it demonstrates that stoichiometry has a major impact on CO emissions, if the engine is within its range of operability in terms of handling fuels.

3. NREL [25] carried out a study with 28 SNREs (Small Non-Road Engines) with four fuels (E0 and splash blended E10, E15, E20). One copy of six different engines was tested on all four fuels using EPA emissions tests or "reasonable surrogates". These engines have open loop control of air-fuel ratio and run on the rich side of stoichiometric, so that adding ethanol leans out the mixture. As expected, when ethanol was added, emissions of HC and CO were reduced, and emissions of NOx increased. This occurred when the engines were new and also at the end of their useful life. Exhaust temperatures increased when ethanol was included in the fuel, increasing 10ºC to 50ºC between E0 and E15.

<u>Operability</u>

1. Orbital Engine Company [50] tested ten two-stroke, 15-hp, outboard marine engines with three fuels (E0 and splash blended E10, E20). In a test at wide open throttle following in-gear low engine speed operation, one engine stalled on E10 and three engines stalled when operating on E20. None of the engines stalled with E0. Furthermore, when operating on E20, the frequency of engine misfire and stall increased, and there was difficulty in maintaining a constant engine speed during the in-gear motoring test.
2. NREL [25] carried out a study with 28 SNREs with four fuels (E0 and splash blended E10, E15, E20). With greater ethanol content, three hand-held trimmers demonstrated higher idle speed and experienced inadvertent clutch engagement. This is a serious safety issue for existing equipment, and EPA must consider how to prevent serious personal injury if these fuels are approved for use.

<u>Materials</u>

1. Orbital Engine Company [44] tested polymeric materials and metals taken from two two-stroke engines – a 15-hp outboard marine engine and an engine from a hand-held line trimmer. Polymeric materials (rubber, plastic, etc.) were tested on gasoline and E20, while metals were tested on E20 only. Significant corrosion was found on a number of metals parts including carburetor body and throttle, pistons, crankshaft bearings, piston rings, and others. All brass components were tarnished, some of them heavily. A number of the polymeric materials showed significant changes with E20 compared to E0. These included the fuel delivery hose and fuel line connector for the outboard engine and crankshaft seal on the line trimmer engine The report concluded that some of the changes were cause for concern and others were unacceptable.

Summary of Non-Road Effects

There is much less data for non-road applications than for on-road vehicles. Emissions effects are likely to be larger because much of the fleet operates on open loop control of stoichiometry. Since many engines operate with rich air-fuel ratios, exhaust NOx emissions and exhaust temperatures are likely to increase with higher levels of ethanol in the fuel. A number of studies raised concerns for the U.S. fleet in terms of driveability, operability and safety (idle speed and inadvertent clutch engagement).

It seems clear that more data should be collected in this area before a conclusion of compatibility can be reached.

TECHNICAL REVIEW OF WAIVER REQUEST

In the waiver request, Growth Energy presents most data as a comparison between E10, which is currently approved, and E15. This comparison is questionable from a regulatory perspective and from a statistical perspective as discussed above.

The waiver request states a number of times that there are "generally" no emissions effects, or that emissions are "*largely* unaffected". This is an oversimplification. One of the studies cited is the NREL study [25], which found that compared to E0, E15 did not significantly increase emissions. Unfortunately, the NOx effect from the NREL report was stated as -1.78% +/- 22.43%. This large confidence interval means that the effect could have been as large as 20% and the program might not have detected it. The finding of "no statistically significant effect" does not mean that an effect does not exist, just that if it is larger than about 20% the program might have found it.

The waiver request did not cite a number of programs that found negative effects on automotive NOx and aldehyde exhaust emissions. [1, 8, 29]

As a result of increased permeation, evaporative emissions with E15 are higher than with E0, even when volatility is closely controlled. This was not acknowledged in the waiver request.

The waiver request did not cite the finding in the NREL study [25] that catalyst/exhaust temperatures in some cars are higher with E15, and that this has negative implications for long term emissions. This has a direct impact on the ability of vehicles to meet emission standards, which have high mileage requirements. The Orbital studies in Australia showed a link between catalyst temperatures and long term durability. [13, 14]

The driveability studies cited in the waiver request [25, 31, 35] all suffered from a serious defect in that they did not compare ethanol and non-ethanol fuels at constant volatility. For instance, in cold weather a splash blended ethanol fuel will have higher vapor pressure and should perform better. The lack of a negative impact is not a good predictor of ethanol's performance in the field where RVPs will be the same.

The waiver request seems to ignore the problems found in non-road engines that were documented in the NREL report. [25] They also did not cite the significant problems with outboard marine engines that were described in the Orbital reports. [44, 50]

CURRENT AND PLANNED PROGRAMS

A number of major programs are under way and others are being planned, indicating that more information is required about the use of blends with more than 10% ethanol.

The Coordinating Research Council, in collaboration with EPA and DOE [51] has defined a number of programs:

- CRC E-87 Catalyst Durability and Degradation - CRC in conjunction with DOE is investigating the issue of catalyst durability and degradation when using ethanol concentrations higher than 10%. This follows on the results from research by Orbital in Australia and DOE, both cited above. Phase 1 has been completed (see below) and Phase 2 is underway.
- CRC E-92 Tailpipe Emissions for SULEV Vehicles at Cold Ambient Temperatures – Starting in 2010, automakers have to meet emission standards at 20ºF in addition to 50ºF. There are concerns that with higher levels of ethanol, such as E15, vehicles will be harder to start at low temperatures and therefore lead to higher emissions. Previous work has suggested that starting at cold temperatures could be a problem for blends with higher levels of ethanol.
- CRC AVFL-15 Fuel Storage and Handling – This project, cofunded with DOE/NREL will determine the durability of wetted engine components/systems that were designed to operate with E10, on higher levels of ethanol.
- CRC CM-136-09 Base Engine Durability – This project will test engine durability for engines designed to operate with E10, when they are operated on gasoline with E20.
- EPA, DOE and CRC (E-89 EPAct Light Duty Vehicle Fuel Effects) – This project will test a number of fuel properties including ethanol content (E0, E10, E15, E20) in a fleet of Tier 2 vehicles.
- CRC E-91 Evaporative Emissions Durability – The objective of this program is to test the immediate and long effects on evaporative emissions of E20 or other mid-level ethanol blends.
- CRC E-90 On-Board Diagnostics (OBD) Evaluation – There is concern among the automakers that the use of E15 and E20 could illuminate the MIL (check engine light) in a substantial fraction of in-use vehicles, often when there is no actual effect on emissions. In the first phase of this study, OBD-related parameters are being recorded from in-use vehicles operating on E0 and E10 fuels.
- CRC CM-138 and others – The CRC is conducting vehicle driveability studies in field test programs to evaluate vehicle performance as a function of fuel ethanol content, under a variety of driving conditions.

There is widespread consensus in the technical community that more data are necessary to understand the effect of intermediate blends of ethanol and gasoline.

CONCLUSIONS AND SUMMARY

A thorough review of the technical literature pertaining to the use of ethanol in gasoline at concentrations higher than 10% was carried out. In addition, the waiver request submitted by Growth Energy to EPA to approve use of E15 was reviewed along with supporting documents.

The consensus of literature reached the following conclusions. Relative to E0, the use of E15 will cause or may cause the following changes in on-road and non-road applications:

- E15 will tend to reduce exhaust emissions of THC/NMOG, CO, benzene and butadiene in on-road and non-road engines.
- E15 will tend to increase exhaust emissions of NOx and acetaldehyde in on-road and non-road engines.
- E15 will tend to raise exhaust gas temperatures in some on-road engines and in most non-road engines. This may have a negative impact on engine and catalyst durability.
- E15 will increase evaporative emissions in on-road vehicles.
- E15 will directionally worsen driveability in some on-road engines and in many non-road engines.
- E15 may cause serious safety hazards, such as inadvertent clutch engagement in non-road engines, which could lead to personal injury.
- E15 may cause premature failure of some parts in some non-road engines.

More data are needed to understand the impact of E15, and a number of programs are being carried out or are being planned to address this need.

LIST OF ACRONYMS

BOB - gasoline Blendstock for Oxygen Blending (may also be referred to as RBOB)

CO – Carbon Monoxide

CRC – Coordinating Research Council, Inc.

DI – Driveability Index

Exx – Ethanol/gasoline mixture, xx represents percent ethanol

FID – Flame Ionization Detector

HC - Hydrocarbon

NMHC – Non-Methane Hydrocarbons

NMOG – Non-Methane Organic Gases

NOx – Oxides of Nitrogen

NREL – National Renewable Energy Laboratory of the Department of Energy

MCAR – Minnesota Center for Automotive Research

MPFI – Multi-point Fuel Injection

OMHCE – Organic Material Hydrocarbon Equivalent

PM – Particulate Matter

RBOB – Reformulated gasoline Blendstock for Oxygen Blending

RVP – Reid Vapor Pressure

SNRE – Small Non-Road Engines

THC – Total Hydrocarbons

Appendix 1

Fuel Properties for Corrosion and Materials Testing

A number of tests were conducted to determine the corrosiveness of fuels and the compatibility of fuels with elastomers and plastics. Most of these used methods defined by SAE and/or ASTM. A problem arises concerning the composition of the fuels to be used when testing ethanol fuels and comparing them to hydrocarbon only fuels.

SAE Recommended Practice J1681 (Gasoline, Alcohol, and Diesel Fuel Surrogates for Materials Testing, Revised January, 2000) defines the composition of fuels for testing. For hydrocarbons, ASTM Fuel C is recommended. Fuel C is a 50/50 mixture of toluene and isooctane. If isooctane cannot be procured, then another isoparaffin is substituted and the mixture is labeled ASTM Surrogate Fuel C (SC).

Ethanol is denatured with 2% CDA 20 (Rubber Hydrocarbon Solvent) which is primarily made up of heptane isomers. When received, ethanol should be mixed with 1% (weight) deionized water. If aggressive ethanol is desired, sodium chloride (0.00048% by weight), sulfuric acid and glacial acetic acid are added as well.

For conducting corrosion tests, SAE J1681 defines corrosive water that may be added to Fuel C or Fuel SC or C/SC with MTBE only. No mention is made of using corrosive water with ethanol blends. Corrosive water contains sodium chloride (0.0165% by weight).

The problem arises when trying to compare different fuel formulations (e.g. E0 and E10), as opposed to qualifying materials for use in engines or fuel systems. If different water phases are used, then the results might not be indicative of the true differences between the fuels. Therefore, it is reasonable to use the same water phase for all fuels in materials testing.

In their reports, Orbital Engine Company disclosed that they used SAE defined corrosive water in the E20 mixtures for all materials testing - corrosion and compatibility. They did not disclose what was used for E0, but it is reasonable to assume that the E0 also used corrosive water, since this is the basis for SAE J1681.

In their work, MCAR used corrosive water only for corrosion testing and only for E0. For ethanol fuels, they used aggressive ethanol as described above.

The issue of how to formulate fuels for comparative testing is being discussed in the technical committees of CRC at this time, and no decision has been reached about future testing.

In any case, the approach adopted by Orbital, while it may be outside the scope of SAE J1681, can certainly be defended as technically justified.

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