Use of Higher than 10 volume percent Ethanol/Gasoline Blends In Gasoline Powered Vehicles

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Nomenclature

AAMA	American Automobile Manufacturers Association
ACEA	Association des Constructeurs Europeens d'Automobiles (or European Automobile Manufacturers Association)
AQIRP	Air Quality Improvement Research Program
ASTM	American Society of Testing and Materials
ATF	Alternative Transportation Fuel
b/d	Barrels/day
CAAA	Clean Air Act Amendments
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPPI	Canadian Petroleum Products Institute
CRC	Coordinating Research Council
DOE	Department of Energy (U.S.)
E10	10 Volume Percent Ethanol
ECP	Environmental Choice Program
EPA	Environmental Protection Agency
ETBE	Ethyl Tertiary Butyl Ether
FIP	Federal Implementation Plan
HC	Hydrocarbons
ISCE	Interdepartmental Steering Committee on Ethanol
JAMA	Japan Automobile Manufacturers Association
MON or M	Motor Octane Number
MTBE	Methyl Tertiary Butyl Ether
NAAQS	National Ambient Air Quality Standards
NO_x	Oxides of Nitrogen
NREL	National Renewable Fuels Laboratory
R&D	Research and Development
RON or R	Research Octane Number
RFG	Reformulated Gasoline
ROS	Renewable Oxygenate Standard
RVP	Reid Vapor Pressure
SAE	Society of Automotive Engineers
SIP	State of Implementation Plan
SwRI	South West Research Institute
U.S.	United States
VOC	Volatile Organic Compounds

EXECUTIVE SUMMARY

Introduction

Ethanol (CHOH) or ethyl alcohol can be produced from agricultural feedstocks such as corn, wheat, barley, and sugar cane. It can also be made from renewable cellulosic materials such as forestry waste, wood waste, and agricultural residues, or it can be derived chemically from ethylene or ethane. Ethanol has a simple molecular structure containing carbon, hydrogen, and oxygen, with well defined physical and chemical properties. Gasoline, on the other hand, is a mixture of hundreds of different hydrocarbons in the range of 4-12 carbon atoms. Gasoline does not contain oxygen.

Ethanol can be used as a transportation fuel in its neat form or as an octane enhancing component in gasoline. Ethanol/gasoline blends, up to 10 volume percent ethanol in gasoline (Gasohol), have been used in conventional gasoline vehicles both in the U.S. and Canada for the last two decades. Initially ethanol was used for energy security and fuel diversity reasons to minimize the dependence on petroleum based fuels. Later on its use was supported for its octane quality and for environmental reasons, since it affects some of the vehicle emissions in a positive manner. At the present time there is a renewed interest in increasing the use of ethanol produced from renewable feedstocks, to minimize the emissions of carbon dioxide - a greenhouse gas which contributes to global warming.

By increasing the amount of ethanol in ethanol/gasoline blends to a maximum limit (beyond the existing value of 10 volume percent), which does not cause any performance or emissions problems in gasoline vehicles, there is a potential to reduce the net carbon dioxide emissions on a vehicle mile basis.

Current Status of Ethanol/Gasoline Blends

At the present time approximately 5.0 billion liters of ethanol are used annually as transportation fuel in the United States. About 10% of total ethanol consumption goes in reformulated gasoline, the oxygenated gasoline program for carbon monoxide control during the winter months uses about 20%, and the remaining 70% is used in gasohol. Gasohol represents roughly 8 to 10 percent of total gasoline sale in the U.S. The U.S. EPA limits the amount of ethanol in ethanol/gasoline blends to a maximum of 10 vol%. However, the increase in RVP which takes place by splash blending of ethanol in gasoline is allowed in the United States.

The current annual ethanol production in Canada is approximately 234 million liters, and it is expected to increase to 675 million liters in near future. Based on the current annual gasoline consumption in Canada, these ethanol production figures represent only about 0.7% and 2.0% of gasoline volume, respectively. In Canada, there is no regulation to limit the volume of ethanol in ethanol/gasoline blends. However, the CGSB standards for ethanol/gasoline blends limit ethanol levels to a maximum of 10 vol%, and they also do not allow any increase in RVP.

All ethanol production in Canada and the U.S. is currently based on renewable agricultural feedstocks such as corn, wheat, etc. The production of ethanol from cellulose, which offers greater reduction in carbon dioxide emissions, is still under development and is not ready for commercialization. Based on current production technology the cost of ethanol is higher than gasoline. The use of fuel ethanol, both in the U.S. and Canada, is being supported by government tax incentives (tax exemption).

Effect of ethanol on Fuel Properties, Vehicle Performance, and Emissions

When ethanol is added to gasoline, it modifies the fuel properties and affects the exhaust and evaporative emissions from the vehicles. Some of the property changes may also affect the vehicle performance. The important property changes include increases in vapor pressure and octane number of the blend compared to base gasoline, enleanment of air-fuel ratio, and the dilution effect of gasoline.

Ethanol/gasoline blends when compared to gasoline, in general, a) increase the evaporative emissions, b) in exhaust they reduce CO, HC, and toxic emissions, increase aldehyde emissions, and may increase NOx, c) on a life cycle basis they reduce carbon dioxide emissions, the amount of reduction depends on the type of feedstock and the ethanol production process. Some older technology vehicles have been reported to encounter hot driveability problems when using ethanol/gasoline blends.

Most of the existing data on the use and effects of ethanol/gasoline blends are limited to ethanol levels up to 10 vol%. To understand the effects of ethanol beyond 10 vol%, on vehicle performance and emissions, it would be necessary to initiate a test program using enhancement benefit and the dilution effect on sulfur, aromatics and olefins in gasoline with increasing ethanol content will certainly be positive.

Synthesis of Telephone Interview, Summary and Recommendations

The automobile manufacturers have announced the “World-Wide Fuel Charter” for gasoline and diesel fuel. In “Category 3” gasoline, the industry is trying to limit the amount of oxygenates for future technology vehicles. Many automobile manufacturers are apprehensive about the effect of ethanol on vehicle performance especially hot driveability, and do not support any increase of ethanol level in blends.

Many petroleum companies view ethanol as a threat to their gasoline market share and are unhappy about government tax incentives for ethanol. The petroleum industry also does not support the notion of increasing the ethanol level beyond 10 vol% in blends.

On the regulatory side, ethanol blends beyond 10 vol% will have to go through a very long and costly waiver approval process in the U.S. No industry or Industry Association in the U.S. is interested in pursuing this path. The ethanol industry, both in the U.S. and Canada, is the continued use of ethanol, as 10 vol% blend in gasoline and as neat ethanol in dedicated engines. Any move in Canada, independent of the U.S., to push this initiative may not get much support.

Production of fuel ethanol from biomass and cellulose feedstocks could help in the reduction of greenhouse gas emissions. However, overall greenhouse gas reduction benefits are directly proportional to the amount of ethanol use, irrespective of the levels of ethanol in gasoline blends.

In view of the extremely small volume of current ethanol production in Canada, if larger volumes of ethanol become available from cellulose based plants at a cheaper cost, there would be plenty of room for increasing the use of ethanol without exceeding 10 vol% in ethanol/gasoline blends.

In the long run, fuel ethanol would have to compete with gasoline in the market place without government tax incentives. Hence a technological breakthrough in the production of ethanol at a cheaper cost is essential for the long term success of ethanol as a vehicle fuel component.

The main advantage of increasing the ethanol level beyond 10 vol% in ethanol/gasoline blends, is to increase the use of ethanol fueling stations. Ethanol would thus replace larger volumes of gasoline in the transportation sector and contribute to reducing greenhouse gas emissions. In order to accomplish it, the following steps are recommended:

a) Initiate a test program to generate vehicle performance and emissions data on higher than 10 vol% blends, using current technology and low emission gasoline vehicles. Ethanol levels of 15 to 17 percent by volume would be a good starting point. If possible, seek the participation of automobile and petroleum industries in this program.

b) If the vehicle performance and emissions results justify the use of higher than 10 vol% blends, get the support of the automotive and petroleum industries in identifying the next steps to bring about this change.

c) Evaluate the impact of a change to higher than 10 vol% in Canada, irrespective of their status in the U.S.

d) Support ethanol production from cellulose to produce larger volumes of ethanol at lower cost.

Use of Higher than 10 volume percent Ethanol/Gasoline Blends in Gasoline Powered Vehicles

1. INTRODUCTION

Ethanol (C2H5OH) or ethyl alcohol can be produced from renewable feedstocks such as corn, wheat, barley, and sugar cane. It can also be made from cellulosic materials such as forestry waste (for example wood-waste and saw dust) and agricultural crop residues, or it can be derived chemically from ethylene or ethane. Ethanol has a simple molecular structure which contains 2-carbon, 6-hydrogen, and 1-oxygen atoms. It also has well defined physical and chemical properties. Gasoline on the other hand is a mixture of hundreds of different hydrocarbons in the range of 4 to 12 carbon atoms.

Ethanol can be used directly as an alternative transportation fuel (ATF) or as an octane enhancing component in gasoline. Ethanol/gasoline blends (up to 10 vol% ethanol in gasoline), also known as “Gasohol” or “E10” (10 denoting 10% ethanol and 90% gasoline), have been marketed in the United States (U.S.) and Canada for the last two decades. Gasohol is used in existing gasoline vehicles without making any changes to the engine or other vehicle components, and without violating manufacturers’ warranties. In contrast, when pure denatured (neat) ethanol is used as a transportation fuel, significant changes to engine and vehicle fuel system are required for reliable operation. This study deals with the possible use of ethanol/gasoline blends at levels higher than 10 vol% ethanol in conventional gasoline vehicles.

1.1 Background

The making of ethyl alcohol is among the earliest of mankind’s application of a chemical process. Natural fermentation of any vegetable matter produces alcohol in varying concentrations. Beer and wine were known to the ancient Egyptians and Mesapotamians. The ancient Chinese are believed to have discovered the art of distillation. In this process, they also discovered the flammable nature of ethanol. Thus, its potential use as a fuel was known in older than written history.

Since the development of internal combustion engine began, ethanol has been continually investigated as an engine fuel. Some of the earliest papers from the Society of Automotive Engineers (SAE) in the U.S. were devoted to alcohol’s fuel properties. In 1933, the Cooperative Fuel Research Subcommittee in the U.S. published a report covering extensive engine testing of ten percent alcohol/gasoline blend. In 1978, the U.S. Congress established the National Alcohol Fuel Commission, consisting of 19 members charged with making a full investigation of the long-term and short-term potential for alcohol fuels from a variety of sources. The act did not differentiate between methanol, ethanol, or any other specific alcohol, using only the generic term, alcohol (1).

The numbers in the parentheses designate the reference given at the end of the report.

The American Society for Testing and Materials (ASTM) established a Task Force on oxygenated fuels such as ethanol. In June 1980, this group proposed a specification for gasohol and for leaded gasohol. On June 30, 1980, President Carter signed into law the Energy Security Act, of which Title 11 consists of the Biomass Energy and Alcohol Fuels Act of 1980.

In Canada, the interest in alcohol fuels started in early 1980's after the upheavals of the 1970's in world oil supply and price. The main issues at that time were the energy security and energy diversity specially in the transportation sector. The environmental issues resulting from motor vehicle emissions were also beginning to emerge. In 1986, a discussion paper on oxygenated gasolines, including ethanol/gasoline blends, was prepared by the Department of Energy, Mines and Resources Canada to help people and organizations make an informed evaluation of the advantages and disadvantages of these fuels. The findings of this paper were discussed by all the stakeholders in a public forum and the final recommendations about the use of alcohol fuels were made by the Standing Committee. The federal government basically supported the recommendations of the Standing Committee. The subsequent developments related to ethanol fuel in Canada are described later in this report.

Thus ethanol fuel, after over 150 years from the time it was first tried in an internal combustion engine is still not the first choice over petroleum based fuels. But as the interests and pressures change over global warming, ambient air quality, air pollution, and energy security, ethanol is still being studied as a potential gasoline component.

1.2 Objective

This study is undertaken to assess the potential of using higher than 10 vol% ethanol/gasoline blends in current and future technology gasoline vehicles. If successful, it can lead to higher consumption and production of ethanol from biomass in Canada, which would replace gasoline and thus contribute to reductions in greenhouse gas emissions.

The objective of this study is to provide the Transportation Systems Division of Environment Canada with sufficient information about:

- the possible use of higher than 10 vol% ethanol/gasoline blends in gasoline powered vehicles from a technical operational and emissions aspect,

- the views of motor vehicle manufacturers and petroleum industry, as well as of various government departments and other agencies on the issue of increasing the ethanol content beyond 10 vol% in ethanol/gasoline blends in Canada

1.3 Methodology

The study included a comprehensive review of the available information on the use of ethanol/gasoline blends in gasoline powered vehicles in the U.S. and Canada. An important component of this study involved telephone interviews and discussions with major motor vehicle manufacturers, petroleum company representatives, government departments, and other relevant organizations both in Canada and the U.S. A questionnaire which was prepared in consultation with the Transportation Systems Division of Environment Canada was used when ever possible during the telephone interviews. The views of various respondents were carefully reviewed and assessed by the author. The summary of this information and recommendations are provided in this report.

2. REGULATORY AND FUEL SPECIFICATION ISSUES

There are many issues concerning the government regulations and fuel specifications which should be met by ethanol/gasoline blends before this fuel can be commercially marketed for use in gasoline powered vehicles. This sections deals with important government regulations and initiatives, and fuel specification issues related to the use of ethanol/gasoline blends both in the U.S. and Canada.

2.1 U.S. Activities

2.1.1 The Clean Air Act

The Clean Air Act of 1970 authorized the U.S. Environmental Protection Agency (EPA) to establish maximum concentration levels called National Ambient Air Quality Standards (NAAQS) for designated pollutants in the ambient, or open, air in order to protect public health "with an adequate margin of safety". Under the Act, the EPA established six NAAQS: three for major automotive pollutants - carbon monoxide (CO), nitrogen oxides (NOx), and ozone or smog; two for pollutants emitted from diesel engines - particulate matter and sulfur dioxide; and the sixth for lead, which has since been phased out from gasoline.

The law requires areas where pollutant concentrations exceed the NAAQS to develop a State Implementation Plan (SIP) to reduce ambient air concentrations to the required levels. There are few states in the U.S. which do not include at least one urban area which is in violation of the NAAQS for either ozone or carbon monoxide. States not complying face possible sanctions on new source construction and freezes in federal grants and highway funds. The Clean Air Act also requires the EPA, where states fail to develop an adequate SIP for attaining NAAQS, to prepare and enforce a Federal Implementation Plan (FIP), in lieu of the SIP. The FIP may include disruptive controls such as downtown parking restrictions, staggered working hours, and other requirements.

The Clean Air Act Amendments of 1990 (CAAA) classified non-attainment areas for ozone, carbon monoxide, and particulate matter in accordance with the severity of the air pollution problem. Table 1 lists the pollution levels corresponding to the various classifications of non-attainment areas. In November 1991 the EPA published its final rule identifying the urban areas in non-attainment for ozone (98 areas) and for carbon monoxide (42 areas).

Table 1
Classification of Non-Attainment Areas

Carbon Monoxide

	Level - ppm	Attainment Date
Moderate	9.1 to 16.4	12-31-95
Serious	16.5 and up	12-31-2000

Ozone

	Level - ppm	Attainment Date
Marginal	0.121 to 0.138	3 years
Moderate	0.138 to 0.160	6 years
Serious	0.160 to 0.180	9 years
Severe 1	0.180 to 0.190	15 years
Severe 2	0.190 to 0.280	17 years
Extreme	0.280 and above	20 years

2.1.2 Oxygenated Gasoline Program

The cities classified in 1992 as serious or moderate non-attainment for CO pollution levels were required to establish oxygenated fuels program. For a period of not less than 4 months during winter each year, the oxygen content requirement for gasoline sold in these cities was a minimum of 2.7 weight percent. On February 5, 1992, EPA published a list of 39 areas required to begin the oxygenated fuels program. The oxygenates primarily used under this program are ethanol and methyl tertiary butyl ether (MTBE). The oxygen content of 2.7% by weight corresponds to about 7.7 volume percent ethanol or 15.0 volume percent MTBE in gasoline.

2.1.3 Reformulated Gasoline Program

The reformulated gasoline program was introduced by EPA in areas classified as extreme or severe for ozone non-attainment beginning January 1, 1995. The CAAA contains a recipe for reformulated gasoline (RFG) by setting maximum and minimum requirements for a number of ingredients. The Act also specifies a set of performance standards in the form of percentages by which volatile organic compounds (VOC) and air toxics must be reduced. Reduction of VOC applies only during summer time, where as toxic reduction applies year-round. From 1995 to 1997 refiners were allowed to use the Simple Model to achieve the required emissions reductions by comparison to the 1990 baseline gasoline. For the years 1998 and later, all refiners must certify their reformulated gasoline by using EPA's Complex Model.

Although only those areas classified as extreme or severe for ozone non-attainment were required to use reformulated gasoline beginning in 1995, the governor of any state containing ozone non-attainment areas of lesser severity may request the EPA to have the reformulated gasoline requirements apply to any or all of those areas as well. This is known as opt-in provision.

The minimum oxygen content for reformulated gasoline was set at 2.0 percent by weight year-round on a pool basis. The reformulated gasoline rule is oxygenate neutral. While the rule does not preclude the use of ethanol, the increase in volatility or Reid Vapor Pressure (RVP) which occurs during splash blending of ethanol in gasoline is not allowed.

In 1994, EPA proposed a rule that would have required at least 30% of the oxygen in reformulated gasoline program to be derived from renewable oxygenates. In proposing its renewable oxygen standard (ROS), EPA was targeting to reduce foreign methanol and MTBE supplies. It also offered CO2 savings over the very inefficient conversion of high quality natural gas to methanol. In its simplest terms, ROS would have meant that 30% of a refiner's RFG must contain 5.6 vol% ethanol. Averaging provisions would allow 16.8% of a refiner's RFG to contain 10% ethanol. This rule could have given a big boost for the use of ethanol as a gasoline blending component, or as a feedstock for ethyl tertiary butyl ether (ETBE). However, this proposal was defeated in the Congress primarily due to the strong opposition by the petroleum industry.

2.1.4 Substantially Similar Regulation

In the U.S. under section 211 (f) (1) of the Clean Air Act, it is unlawful to introduce a fuel or fuel additive into commerce or to increase the concentration of any fuel additive for use in light duty motor vehicles manufactured after model year 1974, which is not "substantially similar" to any fuel or fuel additive utilized in the certification of model year 1975, or subsequent model year, vehicle or engine under section 206 of the Act. Section 206 of the Act sets forth the certification requirements which vehicle manufacturers must comply with in order to introduce into commerce new model year motor vehicles.

However, under section 211 (f) (4) of the Clean Air Act, upon application by any fuel or fuel additive manufacturer the Administrator of EPA may waive the prohibitions of section 211 (f) (1), if the Administrator determines that the applicant has established that such fuel or fuel 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 to which it has been certified. Standards for hydrocarbon, carbon monoxide, and oxides of nitrogen from gasoline powered vehicles have been established under section 202 of the Act.

Under section 211 (f) (4), the following waivers for ethanol/gasoline blends have been granted in the U.S.

- Gas Plus Inc. (December 1978)

Up to 10 volume percent anhydrous ethanol in unleaded gasoline.
Need not meet the ASTM volatility specifications.

This waiver was granted because no decision was taken by EPA within the prescribed 180 days of the receipt of the waiver application.

- Synco 76 Fuel Corporation (May 1982)

10 volume percent ethanol plus proprietary additive.
Must meet the ASTM volatility specifications.

2.1.5 Energy Policy Act of 1992

The primary aim of the energy policy act is to reduce the United States' dependence on crude oil imports. It provides federal mandates for alternative fuel vehicles. Titles III, IV, V and VI address provisions regarding alternative fuels and alternative fuel vehicles. Title XIX addresses energy conservation and production incentives, whereas Title XII addresses provisions regarding the production, utilization, and technological advancement of renewable energy.

The Act sets specific goals for the "Alcohol From Biomass Program", as follows:

- reduce the cost of alcohol to $0.70 per gallon.
- improve the overall biomass carbohydrate conversion efficiency to 91%.
- reduce the capital cost component of the cost of alcohol to $0.23 per gallon.
- reduce the operating and maintenance component of the cost of alcohol to $0.47 per gallon.

In addition, the existing tax exemption for gasoline containing 10 percent ethanol was extended to include lower level blends up to 5.7 percent ethanol.

2.1.6 Ethanol Incentives

Based on the Energy Tax Act of 1978, the U.S. government allows $0.54 per gallon of ethanol as federal tax credit for companies using ethanol in ethanol/gasoline blends. The government also offers a producer tax incentive of $0.054 per gallon of ethanol produced. In 1990 this credit was extended to include ethanol used in the production of ETBE. The tax credit is currently good to the year 2000. Recently, the U.S. Senate (March 11, 1998) and the U.S. House of Representatives (May 22, 1998) have both overwhelmingly voted to extend the ethanol tax incentive through the year 2007 as part of the six year federal highway reauthorization bill. Many states also offer economic incentives for the use of ethanol. These are listed in Table 2.

Table 2
States With Ethanol Incentives *
(Dollars per Gallon)

State	Fuel Tax Exemption on Blended Fuel	Producer Incentive
Alaska	0.08	
Connecticut	0.01	
Hawaii	exempt from standard excise tax on retail sales (4%)	
Idaho	up to 10% of excise tax on gasoline	
Illinois	0.0185	
Iowa	0.01	0.20
Kansas		0.20
Minnesota	0.02	0.20
Missouri	0.02	0.20
Montana		0.30
Nebraska		0.20
North Carolina		Income tax credit up to 30% of plant cost
North Dakota		0.40
Ohio	0.01	
Oregon	0.05	50% property tax exemption for in-state ethanol production facilities
South Dakota	0.02	0.20
Washington		Credit of 60% of tax rate for each gallon of ethanol blended
Wyoming	0.04	

***** Information taken from Ref. (2)

2.2 Canadian Activities

2.2.1 "EcoLogo" to Ethanol/Gasoline Blend

The Environmental Choice Program (ECP), managed at arms length from the federal government, granted an "EcoLogo" to ethanol/gasoline blends in 1990. The comments by Environment Canada on the submission to the ECP acknowledged that ethanol/gasoline blends could provide potential environmental benefits. The brief also recommended that the ECP guideline establish strict fuel blending control to ensure that the volatility of ethanol blends is matched with that of commercial gasoline.

2.2.2 Government Support to Ethanol

In March 1991, an Interdepartmental Steering Committee on Ethanol (ISCE) was formed under the joint chairmanship of the Departments of Agriculture and Natural Resources Canada (then Energy, Mines and Resources Canada) to prepare recommendations for promoting the use of fuel ethanol in Canada. The February 1992 federal budget removed the federal excise tax of $0.085 per liter (now $0.10 per liter) from the biomass derived ethanol portion of ethanol/gasoline blends. This measure provided the same treatment to ethanol blends as to other alternative fuels used in the transportation sector. In November 1992, the federal government announced a five-year $12 million initiative to encourage the production and use of biomass ethanol.

Federal government under its National Biomass Ethanol Program also allocated $70 million as contingent line of credit (loan guaranty) for qualified ethanol producers for the period of 1999 to 2005. This program is monitored by the Farm Credit Corporation, and the line of credit can only be used in the event of federal tax incentive for ethanol being withdrawn. Till today only Commercial Alcohol has qualified for the line of credit for an amount of $32 million.

Besides the federal government, some provinces in Canada also provide incentives for ethanol/gasoline blends. The details are provided in Table 5.

2.2.3 Bill C-226

In March 1993, Private Member Bill C-226, which proposed mandating the use of 3.2 weight percent oxygen and elimination of octane enhancer MMT (methylcyclopentadienyl manganese tricarbonyl) from gasoline, was defeated in the House of Commons. The federal departments of Environment, Transport, Natural Resources, and Health did not support the Bill. The principal reasons cited by departments opposed to the Bill included:

- The mandated use of 3.2 wt% oxygen in gasoline is not justified on the basis of environmental benefits and would pose undue hardships on the petroleum industry to find sufficient quantity of oxygenates to meet the proposed standard;
- The existing data on the effect of MMT on exhaust emissions is inconclusive. At the present time, there is no evidence of any adverse health effects related to MMT's use in gasoline; and
- The development of a fuel strategy is best approached through the involvement of fuel producers, engine and vehicle manufacturers, government and fuel standard setting agencies.

2.2.4 Alternative Fuels Act

The Alternative Fuels Act was proclaimed as a law in Canada on June 22, 1995, with the passage of Bill S-7. The Act mandates the increasing use of alternative fuel vehicles in the federal government fleet where it is cost-effective and operationally feasible. The alternative fuels included in this Act are ethanol, methanol, propane, natural gas, hydrogen, and electricity when used as a sole source of direct propulsion energy.

The Treasury Board of Canada issued the new “Motor Vehicle Policy” which became effective on June 19, 1996, for the federal government fleet vehicles. This policy on the use of alternative fuels states that, where it is cost effective and operationally feasible to do so, a federal body shall use an alternative fuel in operating any vehicle that can operate on such a fuel (it includes the use of ethanol/gasoline blends).

3. CURRENT STATUS OF ETHANOL/GASOLINE BLENDS AS A MOTOR VEHICLE FUEL

The current use of ethanol/gasoline blends in the U.S. and Canada is limited to ethanol concentrations of 10 vol% or lower. This is primarily based on the maximum permissible amount of ethanol approved by EPA for use in gasoline blends. Secondly, the current cost of ethanol in comparison of gasoline price, is not sufficiently attractive to generate interest in marketing higher than 10 vol% blends.

3.1 Ethanol Use in the U.S.

At the present time about 1.3 billion gallons (approximately 5.0 billion liters) of ethanol are used annually in three distinct markets in the U.S.

- Reformulated gasoline (RFG),
- Oxygenated gasoline (carbon monoxide control), and
- Gasohol (10 vol% ethanol blends).

The amount of ethanol going into RFG is small and uncertain. It is estimated to be about 10% of current ethanol production, with some seasonal swing toward greater use in winter. It is too costly to reformulate summer RFG to utilize ethanol and meet RVP requirements or to convert ethanol into ETBE relative to the cost of MTBE. It is also not likely that refiners will switch from MTBE in summer to ethanol in the winter. Therefore the ethanol market in RFG is not likely to expand beyond its current share.

The use of ethanol in oxygenated gasoline, for CO control during the winter months in certain urban areas, is estimated at about 20% of current production. The remainder, about 70% of total ethanol production is used in gasohol - as a gasoline extender or octane enhancer. The current average market share of gasohol is between 8 to 10% in all areas not requiring reformulated gasoline. The economic competitiveness of gasohol is dependent on gasoline prices and the net production cost of ethanol.

In the state of Illinois, ethanol/gasoline blends account for approximately half of all motor fuel sold. Ethanol industry currently supplies 95% of Chicago's oxygenate requirements. Ethanol also enjoys a near 100% market share in virtually every other market west of Rockies that utilizes oxygenated gasoline to reduce CO and ozone pollution (Seattle, Portland, Phoenix, Tucson, Las Vegas, and Reno). Ethanol is currently marketed in every state except California, where MTBE has been the mandated oxygenate because of the state's regulatory barriers that effectively prohibit the use of ethanol. The ethanol industry and its supporters are making various efforts to change this situation. There is a move to raise the "cap" on the use of oxygenates from the current level of 2.7 wt% to 3.5 wt% oxygen content in California reformulated gasoline. The staff of the California Air Resources Board (CARB) is supportive of this change and a final submission to the Board will be made in December 1998. The other related issue is the current "cap" of 7.0 psi on RVP for California reformulated gasoline. So besides raising the "cap" on the amount of oxygen, ethanol supporters also want to raise the "cap" on RVP. The mood in

CARB is to provide more flexibility to refiners in choosing the oxygenate. If approved by the Board, the new regulation will open up the California market for ethanol and provide oxygenate options other than MTBE to refiners. It should be mentioned that the use of MTBE in California gasoline is coming under very tight scrutiny due to recent incidents of water pollution problems caused by leaks from the underground gasoline tanks. Approximately 50,000 barrels/day (b/d) of ethanol would be required to meet California's oxygenate demand. The entire U.S. industry currently produces 85,000 b/d but existing production capacity exceeds 110,000 b/d (3).

As discussed earlier, there are a number of policy initiatives in the U.S. which support the use of ethanol as transportation fuel. The $0.54 per gallon tax subsidy is the most important and is the driver of current ethanol market. This is augmented by the requirement for the use of oxygenates in about 30% of U.S. gasoline (RFG and Oxygenated gasoline mandates) as a pollution abatement strategy. In addition, ethanol used in conventional gasoline has a waiver from vapor pressure requirements that helps reduce the cost of using it in gasohol.

The other important government policy involves a US$20 to US$25 million per year commitment to research and development (R&D) on the advancement of ethanol production technologies. Finally, as part of an overall greenhouse gas reduction policy biomass derived fuels, specially ethanol, are getting increased attention. The greenhouse gas reduction strategy would have little effect on corn-based ethanol but could provide significant support to cellulosic ethanol.

A recent U.S. Department of Energy study (4) concluded that under current tax incentives cellulosic ethanol could be one of the key fuels that could achieve the 30% petroleum replacement goals of the U.S. Energy Policy Act, as well as provide significant reductions in greenhouse gas emissions from transportation sector. Two possible transition pathways for ethanol in the U.S. were examined: one for production/feedstock - grain to cellulose, and the other for end use - from low level blends to neat fuel use.

The transition in ethanol production from grain to cellulose is outside the scope of this study and will not be discussed further. The possible transition from current ethanol market and end use and market to significantly higher use considered by the U.S. Department of Energy included:

- Expansion of the low level ethanol/gasoline blends (10 vol% ethanol) market beyond its current 8 to 10% market share to all areas not requiring reformulated gasoline;
- Increase in the blend level of ethanol (from current 10 vol%) to highest level possible while maintaining acceptable conventional gasoline vehicle operation; and
- Use of neat (or near-neat) ethanol in specially designed vehicles.

For the end use transition analysis, it was assumed that in low level ethanol/gasoline blends the ethanol level can be increased from 10 to 17 vol% , without making any adverse effect on vehicle operation or consumer acceptance. However, this assumption was not validated by the views from the motor vehicle manufacturers. The study discussed the implications of increasing the ethanol market and made estimates for the cost of increasing the utilization of ethanol.

3.2 Ethanol Use in Canada

The current ethanol production in Canada is approximately 234 million liters per year, or about 61.6 million U.S. gallons/year (5). The potential future ethanol production in Canada is estimated at 675 million liters per year. The information about the existing and proposed ethanol plants in Canada is shown in Table 3. For obvious reasons, fuel ethanol development in Canada has been slow compared to the United States. First of all, there is no mandate for the use of reformulated gasoline or oxygenated gasoline in Canada. Secondly, the Canadian General Standards Board (CGSB) specifications for ethanol/gasoline blends do not allow higher volatility than for the commercial gasoline.

Table 3
Operational and Proposed Ethanol Plants in Canada

Existing Ethanol Plants

Operator	Location	Production/Yr.	Year
Mohawk Canada Ltd.	Minnedosa, Man.	10 M Liters	1980
Tembec	Temiscaming, Que.	17 M Liters	1985
Commercial Alcohols	Triverton, Ont.	23 M Liters	1989
Pound-Maker Agventures	Lanigan, Sask.	12 M Liters	1991
Commercial Alcohols	Chatham, Ont.	150 M Liters	1997
Agri-Partners International	Red Deer, Alberta	22 M Liters	1998
Total Production		234 M Liters	

Proposed Ethanol Plants

Operator	Location	Production/Yr.	
Commercial Alcohols	Chatham, Ont.	150 M Liters Expansion	
Commercial Alcohols	Varennes, Que.	150 M Liters	
Seaway Grain Processor	Cornwall, Ont.	66 M Liters	
Metalore Resources, Inc.	Unknown	75 M Liters	
Total Future Production		675 M Liters	

Nearly all of the fuel ethanol in Canada is being used as low level ethanol/gasoline blends at 10 vol% or lower. The percentage of ethanol in various ethanol/gasoline blends currently being marketed in Canada is shown in Table 4 (5).

The current gasoline consumption in Canada is approximately 34 billion liters per year. The existing ethanol production of 234 million liters is less than 0.7% of gasoline volume. Even the future ethanol production, when it reaches 675 million liters per year, will be less than 2% of gasoline consumption. So in future if 10 vol% ethanol blends are to be used, there would be sufficient ethanol only for 1/5 th of the total gasoline sold in Canada.

Table 4
Percentage of Ethanol in Blends

Company	Vol % Ethanol in Blend
GraHam Energy	8%
MacEwen Petroleum	10% (in Ethanol Mix Product)
Mohawk Canada Ltd.	10% (in all “Premium Plus” blends)
	10% (in “Regular Plus” blends in Ontario, Manitoba, and Saskatchewan)
	5% (in “Regular Plus” blends in Alberta and British Columbia)
Mr. Gas	6% (only in “Ethanol Plus” blend)
Pioneer Petroleum	8% (only in Magnum 93)
Sonic	5%
Sunoco	8% (all blends)
United Farmers of Alberta (UFA)	10%
UPI Inc.	8% (all blends)
Ontario and Quebec based independents supplied by Coastal Canada (including Drummonds, Francis Fuels, Sunys, W.O. Stinson)	Between 5.5 and 6%

Like in the U.S., federal and provincial tax incentives for ethanol, which started in 1992, have been the major drivers for the ethanol market in Canada. The list of federal and provincial tax incentives on ethanol/gasoline blends is given in Table 5 (5). As of February 1998, there are 929 fueling outlets for ethanol/gasoline blends in Canada. These retail outlets are distributed in six provinces of Canada: Ontario 520, Québec 125, Alberta 110, British Columbia 106, Manitoba 35, Saskatchewan 32, and Yukon only 1.

According to the Canadian Renewable Fuels Association , the energy efficiency of ethanol production from grain (corn, wheat, barley) is higher in Canada than the U.S. because of a much lower dependence on irrigation for grain production in Canada. An independent analysis made in 1992 showed that ethanol made from Ontario grown corn had over twice the combustible energy compared to the energy used in its production. The ratio of energy content to energy required for ethanol production is about 1.7 : 1 in the U.S. The co-products of Canadian ethanol production, which include high-protein food and feed ingredients, are generally used close to the site of production, and also replace large imports of soybean meal from the U.S.

Table 5
Canadian Tax Incentives for Ethanol/Gasoline Blends

Region	Description	Incentive on E10 in Cents/L	Total Tax Incentive on E10 (Fed+Prov) in Cents/L
FEDERAL	Excise Tax on Gasoline	1.0	
PROVINCIAL			
Newfoundland		None	1.0
Prince Edward Island	No ethanol blends in P.E.I.	-	1.0
Nova Scotia		None	1.0
New Brunswick	Ethanol blends not allowed	-	-
Québec	Effective January 1999	2.0	3.0
Ontario	Road Tax	1.47	2.47
Manitoba	Only for E10	2.5	3.5
Saskatchewan	Under Negotiation	None	1.0
Alberta	Fuel Tax	0.9	1.9
British Columbia	Only for E85	-	1.0
Yukon		None	1.0
Northwest Territories		None	1.0

In response to air quality concerns, a bill has been introduced in the province of Ontario to mandate the use of ethanol/gasoline blends with a minimum of 6 vol% ethanol (6). This bill introduced by the Member of Parliament (MPP), Jack Carroll, from Chatham-Kent, has passed the second reading in the legislature and is supported by the Conservative caucus and both opposition parties. The Ontario Corn Producers Association note that a billion liter market for ethanol in Ontario would utilize 100 million bushels of corn, generating $400 million.

Based on a recent paper study (7) it is estimated that Canada has a potential to produce 3.3 billion liters of renewable ethanol from residues, lower grade grain, and lignocellulosic materials planted for biomass purposes.

4. EFFECT OF ETHANOL ON FUEL PROPERTIES

Ethanol has been widely used in the U.S. as a gasoline component since the late 1970s when it was used as a fuel extender due to gasoline shortages. Later, when gasoline was more plentiful, ethanol began to see widespread use as an octane enhancer. When ethanol is added to gasoline, it modifies the fuel properties and affects the nature and quantities of exhaust and evaporative emissions from vehicles. This section covers the effects of fuel property changes related to the addition of ethanol to gasoline. Clear understanding of these effects is very important in evaluating the technical and performance related issues when considering the use of higher than 10 volume percent ethanol blends in gasoline.

The principal changes in the fuel property due to the addition of ethanol to gasoline include:

- Effect on Octane Number,
- Effect on fuel volatility; V/L ratio, Reid Vapor Pressure (RVP),
- Effect on distillation curve; T10, T50, and T90,
- Enleanment effect of ethanol,
- Effect on fuel economy, and
- Effect of water solubility and phase separation.

Table 6 shows the properties of ethanol and gasoline which play important roles in altering the fuel properties of ethanol/gasoline blends.

Table 6
Some Properties of Ethanol and Gasoline (8, 9)

Property	Units	Ethanol	Gasoline
Formula	-	C2H5OH	C4 to C12 compounds
Molecular Wt.	-	46.07	1400-105
Composition	Weight %		
Carbon		52.2	85-88
Hydrogen		13.1	12-15
Oxygen		34.7	0
Boiling Temp.	°C	78.3-78.5	27-225
	°F	172-173	80-437
Density	kg/L	0.792	0.72-0.78
	lb/gal	6.61	6.0-6.5
RVP	kPa	15-17	50-100
	psi	2.3-2.5	8-15
Blending RVP	kPa	118-144	50-100
	psi	18-22	8-15
Heat of Vaporization	kJ/kg	842-930	330-400
	Btu/lb	362-400	140-170
Lower Heating Value	kJ/kg	27,000	43,000
	kJ/L	21,200	31,800
	Btu/lb	11,600	18,500
	Btu/gal	76,000	114,000
Autoignition Temp.	°C	365-425	257
	°F	689-797	495
Flammability limits	vol%	3.3-19.0	1.0-8.0
Stoichiometric A/F	kg/kg	8.9-9.0	14.5-14.7
Equivalent Volume, LHV	L/L of Gasoline	1.53	1.0
RON	-	102-130	90-100
MON	-	89-96	80-92
(R+M)/2	-	96-113	85-96
Blending RON	-	112-120	90-100
Blending MON	-	95-106	80-92
Viscosity	Centipoise at 20°C	1.19	0.37-0.44
	Centipoise at -20°C	2.84	0.60-0.77
Water Solubility	Vol% at 21°C	100	Negligible
Carbon dioxide	kg/kg Fuel	1.91	3.18

4.1 Effect of Ethanol on Octane Number

Octane number is a measure of the resistance of a fuel to autoignition. It is also defined as a measure of antiknock performance of a gasoline or gasoline component. The octane value posted on retail gasoline pumps is the average of the "Research" (RON or R) and "Motor" (MON or M) octane numbers, or "(R+M)/2". The standard tests for RON and MON are not completely applicable to ethanol. There is a great deal of scatter in RON and MON values reported for ethanol in the literature. Nevertheless, there is general agreement that ethanol has excellent antiknock properties allowing higher compression ratios and improved engine efficiencies (10).

Since ethanol has higher octane than many gasoline components, when added to gasoline it increases the octane value of the finished fuel. The blending octane values shown in Table 6 indicate that ethanol boosts research octane to a greater extent than motor octane. Hence it is possible for an ethanol/gasoline blend, with the same posted octane rating as a non-oxygenated gasoline, to have a slightly lower motor octane level.

Some engines respond more strongly to motor octane than research octane. At high speeds or under heavy load conditions, for instance when pulling a trailer up a hill, motor octane is a better indicator of antiknock performance. For these engines, a small reduction in motor octane could result in a slightly higher incidence of engine performance problems, such as engine knock, dieseling, or increased temperature. Over time, severe engine knock can lead to damaged pistons or other engine damage.

Most late model cars in the U.S. and Canada have been equipped with electronic knock sensors that detect combustion knock and signal computers to retard the ignition timing and reduce the knock. The automatic ignition retardation could diminish engine power to an extent that might be recognized as a loss in performance by some drivers. It has been reported that ethanol/gasoline blends have superior resistance to combustion knock at low engine speed and deter run-on (the tendency of the engine to continue to run after the ignition has been turned off) largely because of their higher heat requirement for vaporization (11). Higher RON gasolines also reduce run-on.

Although ASTM does not specify a minimum standard, it recommends that gasolines with a (R+M)/2 octane value of 87 have a minimum motor octane of 82. Some refiners have their own internal minimum motor octane performance values for their gasolines.

4.2 Effect of Fuel Volatility on Vehicle Performance

A fuel's ability to vaporize or change from liquid to vapor is referred to as its volatility. Volatility is an extremely important characteristic of gasoline which affects many vehicle performance parameters. Table 7 lists the effects of gasoline volatility on vehicle performance. The effects of volatility on vehicle performance are also shown graphically in Figure 1.

For example, if the volatility curve in Figure 1 moves down in the initial range of up to 30% evaporated, then more fuel would vaporize at lower temperatures and it may cause poor hot starting and vapor lock problems. The effects of shifting the volatility curve in the mid and higher percent evaporated ranges are also clearly marked on Figure 2.

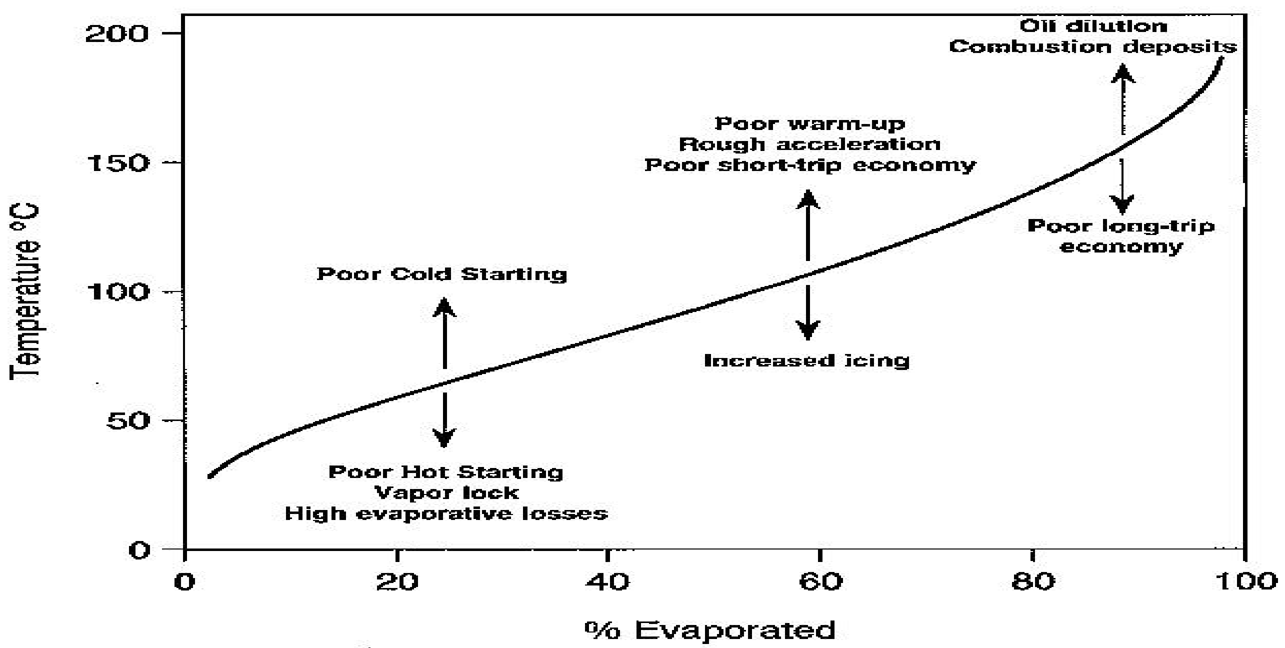

Figure 1 The Effect of Volatility on Vehicle Performance

Table 7
Effects of Gasoline Volatility on Vehicle Performance

Volatility Too Low	Volatility Too High
Poor cold start	High evaporative emissions, Canister overload & Purge
Poor warm up performance	Hot driveability problems, Vapor lock
Poor cold weather driveability	Fuel economy may deteriorate
Unequal fuel distribution in carbureted vehicles	
Increased deposits: crankcase, spark plugs, combustion chamber	

Gasoline which is not volatile enough results in poor cold start and poor warm up driveability as well as unequal distribution of fuel to the cylinders in carbureted vehicles. These fuels can also contribute to deposits in crankcase, spark plugs, and combustion chamber. Gasoline which is too volatile vaporizes too easily and may boil in fuel pumps, lines or in carburetors at high operating temperatures. If too much vapor is formed, this could cause a decrease in fuel flow to the engine, resulting in symptoms of vapor lock, including loss of power, rough engine operation, or complete stoppage. Fuel economy could also deteriorate and evaporative emissions could increase.

In order to assure that fuels possess the proper volatility characteristics, refiners adjust gasoline seasonally, providing more volatile gasoline in winter to offer good cold start and warm up performance. In summer, gasoline is made less volatile to minimize the vapor lock and hot driveability problems, and also to comply with environmental standards.

The main parameters to establish volatility limits are Vapor/Liquid Ratio (V/L), Vapor Pressure, and Distillation Curve. ASTM provides standards for one or more test procedures to measure each of these parameters.

The vapor/liquid ratio uses a test to determine the temperature required to create a V/L ratio of 20. This ratio can also be calculated for gasolines using a combination of distillation and vapor pressure characteristics. More volatile fuels require lower temperatures to achieve this ratio while less volatile fuels require higher temperatures to create the same ratio. The V/L ratio assists in defining a fuel's tendency to contribute to vapor lock.

According to one of the ASTM test procedures, Reid vapor pressure (RVP) is measured by submerging a gasoline sample, sealed in a metal chamber, in a 100°F water bath. More volatile fuels will vaporize more readily, and give higher vapor pressure reading. Less volatile fuels will generate less vapor and therefore give lower reading. Because of the popularity of this test method, RVP has become a widely used term when referring to vapor pressure of fuels.

The V/L ratio and RVP are measurements of a fuel's "front end volatility", or more volatile components which vaporize first. The distillation test is used to determine fuel volatility over the entire boiling range of gasoline. Gasoline consists of a variety of hydrocarbon components that evaporate at different temperatures. More volatile components evaporate at lower temperatures, less volatile ones at higher temperatures. The plot of these evaporation temperatures is referred to as a distillation curve. The ASTM specification sets temperature ranges at which 10%, 50%, and 90% of the fuel will be evaporated as well as at the temperature at which all the fuel would evaporate (referred to as "end point"). Each of these points affect different areas of vehicle performance as shown in Figure 1.

The 10% evaporated temperature must be low enough to provide easy cold starting but high enough to minimize vapor lock and hot driveability problems. The 50% evaporated temperature must be low enough to provide good warm up and cold weather driveability without being so low as to contribute to hot driveability and vapor lock problems. The mid boiling range of gasoline also affects short trip fuel economy. The 90% and end point evaporation temperatures must be low enough to minimize crankcase and combustion chamber deposits as well as spark plug fouling and dilution of engine oil.

4.2.1 Effect of Ethanol on Fuel Volatility

Ethanol has a fixed boiling point and thus a constant volatility, while the volatility of gasoline can be tailored over a range by adjusting the relative amounts of different hydrocarbon components. Adding ethanol to gasoline depresses the boiling temperature of individual hydrocarbons. It depresses the boiling point of aromatic hydrocarbons slightly less than aliphatic hydrocarbons. The effect of ethanol addition on the shape of a distillation curve is shown in Figure 2 (12). As the data indicate ethanol/gasoline blend (10 vol% ethanol) has significantly lower temperatures for evaporation of the front end, which affects primarily the first 50% evaporated. If ethanol concentration in the blend is increased beyond 10 vol%, the volume of the fuel evaporating under 200°F will increase, and the distillation curve for these blends will be lower than the curve for 10 vol% blend shown in Figure 2.

Vapor pressure is another important volatility parameter of gasoline that is affected by the addition of ethanol. As shown in Table 6, the RVP of ethanol is much lower than the RVP of gasoline. However, blending ethanol into gasoline forms a non-ideal solution that does not follow linear blending relationships. Rather than lowering the vapor pressure, low concentrations of ethanol cause increase in RVP as shown in Figure 3 (12). The vapor pressure increase due to ethanol reaches a maximum value around 5 vol% ethanol content, and then it starts to come down with the increase in ethanol concentration. Thus blends with greater than 10 vol% ethanol will give a smaller increase in RVP. It has also been reported that with the addition of ethanol, gasolines with lower vapor pressures incur larger increases in vapor pressure than gasolines with higher vapor pressures (13). The data are shown in Figure 4.

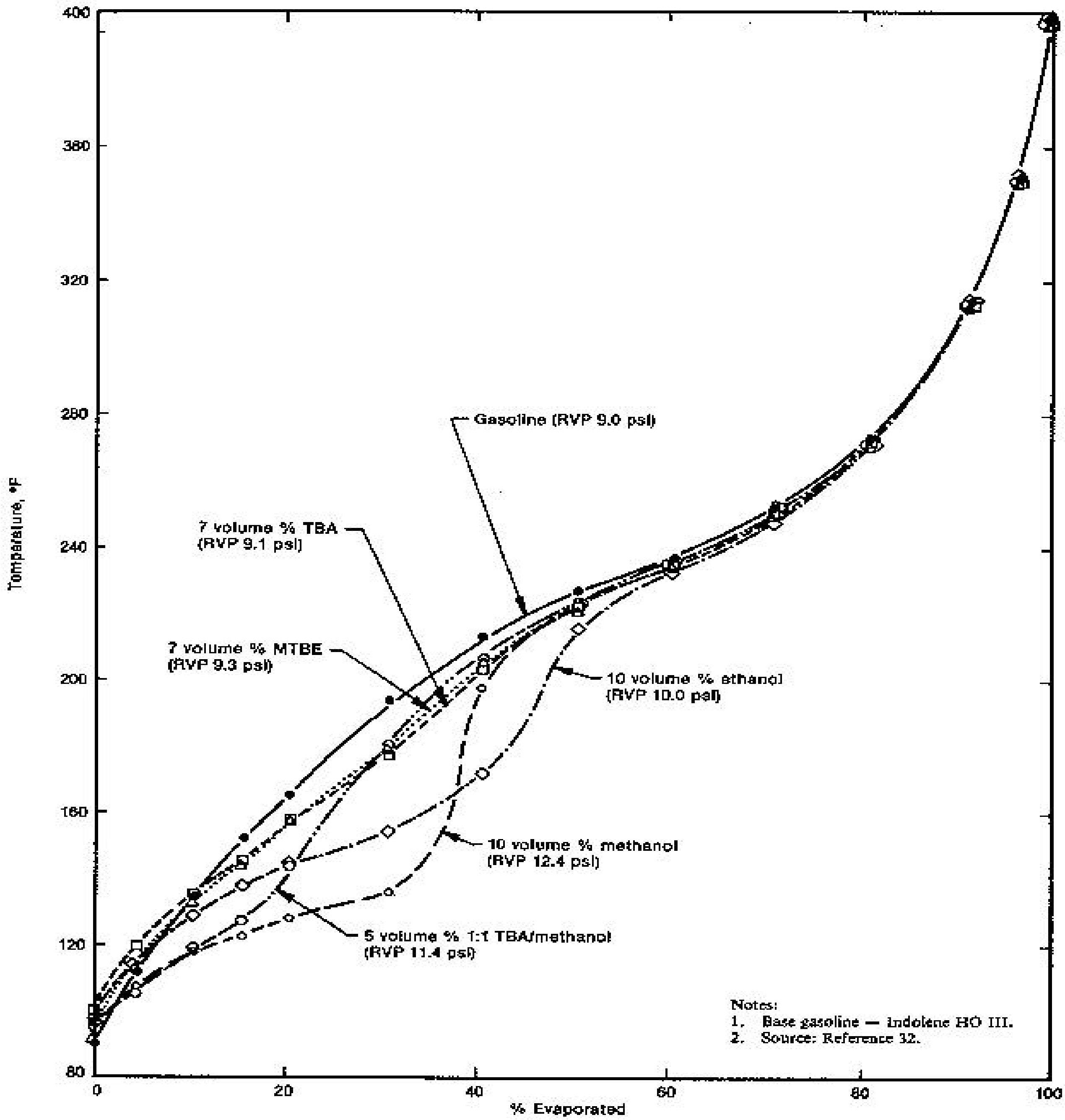

Figure 8—Effect of Oxygenates on Distillation

Figure 2 Effects of Oxygenates on Distillation Curve

When ethanol/gasoline blends are commingled with gasoline, as they might be during the routine fill up of vehicle fuel tanks, the RVP effects of ethanol are similar to those discussed above (14). The data in Figure 5 (15) show that mixing an ethanol/gasoline blend with gasoline of the same RVP results in substantially increased vapor pressure. Calculations of temperatures for specific V/L ratios of ethanol/gasoline blends using ASTM procedures developed for gasolines do not predict measured values. Figure 6 shows how the addition of ethanol changes the temperatures at which various V/L ratios occur (16). For example, the reference gasoline reaches a V/L ratio of 20 at a temperature of 160°F. Adding 10% ethanol to the reference gasoline reduces this temperature to 138°F. The V/L ratio data for ethanol blends greater than 10 vol% is not readily available. However, it can be predicted that the temperature to achieve the V/L ratio of 20, for higher than 10 vol% blends, will be less than the corresponding temperature for 10 vol% blend.

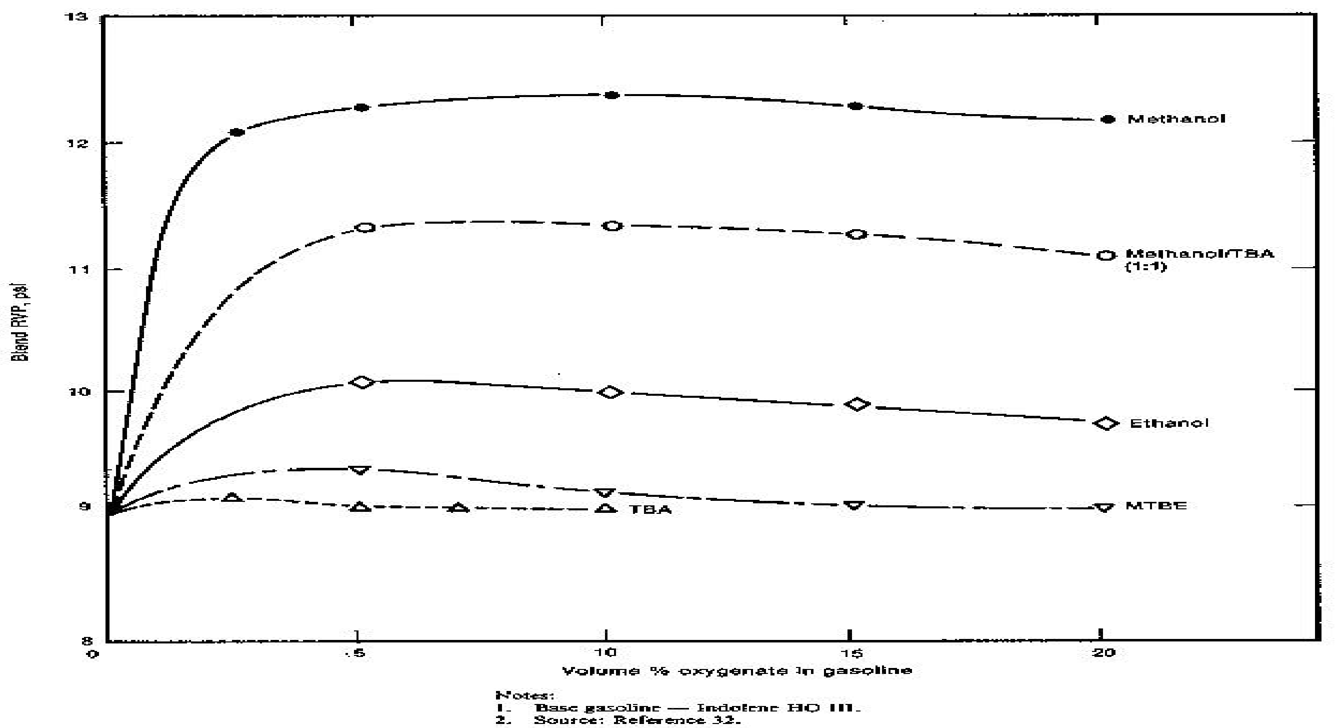

Figure 3 Effect of Ethanol Concentration on Blend Vapor Pressure

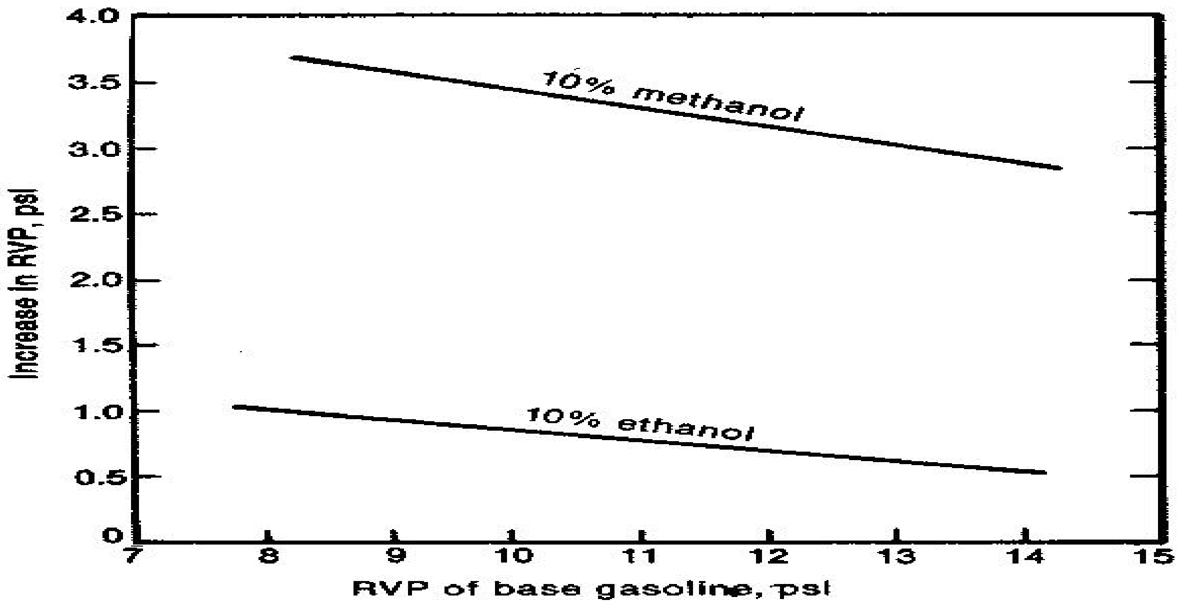

Figure 4 Effect of Base Gasoline RVP on RVP Increase Due to Ethanol Addition

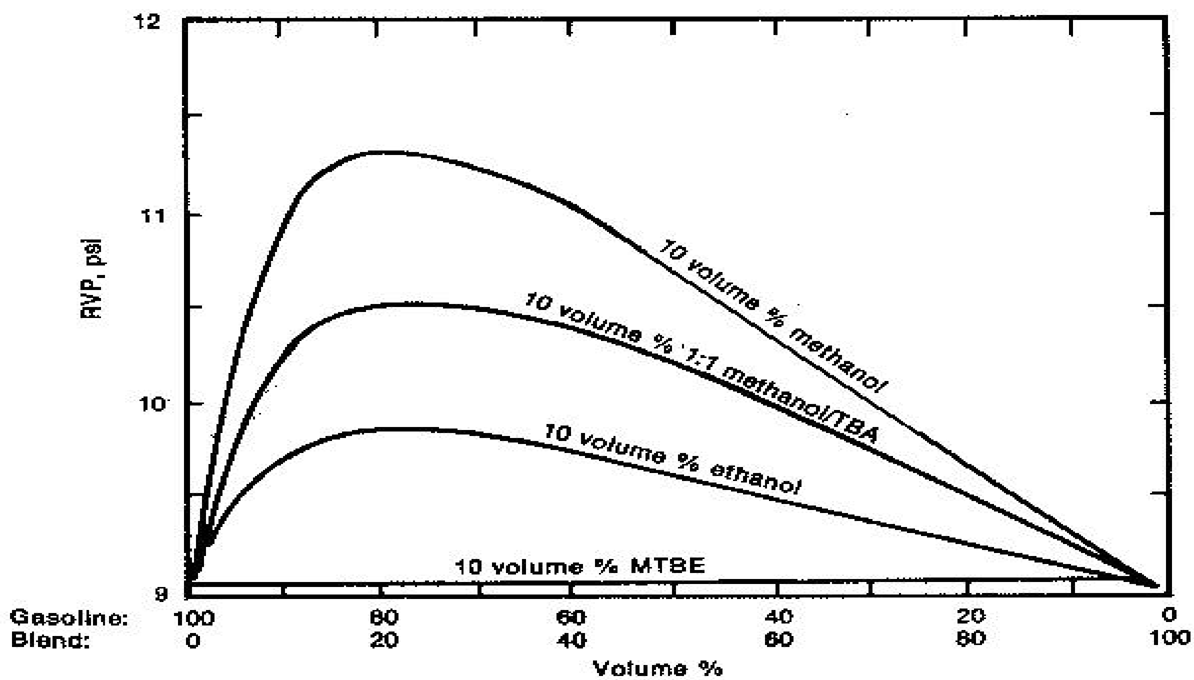

Figure 5 Effect of Commingling a Gasoline and an Ethanol Blend of Same RVP

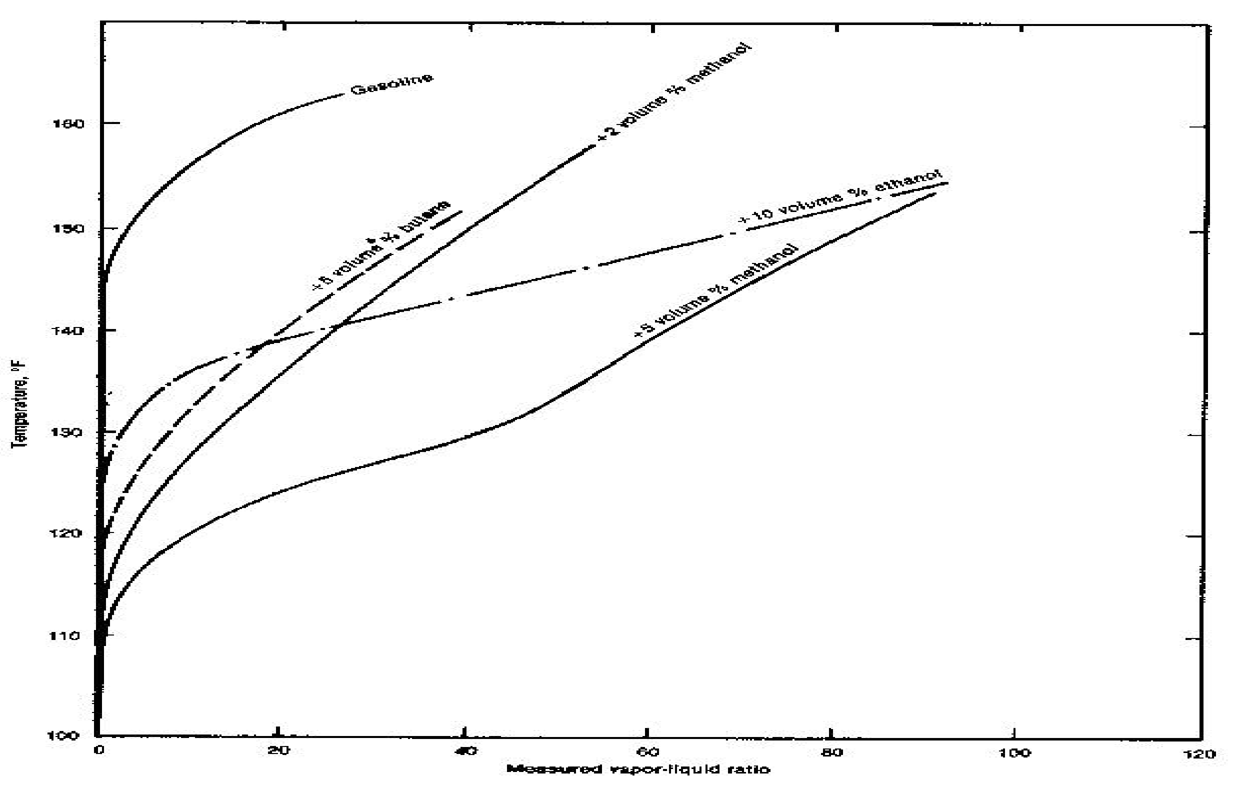

Figure 6 Effect of Ethanol on Measured Vapor to Liquid Ratio

4.2.2 Effect of Ethanol/Gasoline Blends on Vehicle Performance

In order to start cold engine, sufficient amount of fuel must be present in vapor form in the engine cylinders to initiate and sustain combustion. Generally, for gasoline, increased RVP and lower front-end distillation temperature improve cold starting performance. However, ethanol/gasoline blends can behave slightly differently than gasoline. Ethanol blends will require more heat to vaporize than gasoline. For example, a blend containing 10% ethanol needs 16.5% more heat to vaporize completely than does gasoline. Some concerns have been raised about difficulty in starting vehicles using blends at extremely low temperatures (8). 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 solubility.

At moderate temperatures, vehicle driveability becomes an important issue. Through many years of cooperative research the auto and oil industries have evaluated driveability from the viewpoint of the driver and have developed rating methods that quantify driveability. Factors that contribute to a good driveability rating include 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 conditions as the car is driven through a prescribed cycle. The Coordinating Research Council (CRC) has established procedures for measuring driveability (10).

A number of extensive road test programs have been conducted by several organizations to assess the influence of oxygenated blends on the driveability of vehicles that embodied various technologies. Based on the results of several driveability programs, conducted at ambient temperatures ranging from 30°F to 83°F, commercial gasolines were at least 98 percent problem-free. Among the blends tested, gasohol was closest to gasoline in the frequency of reported problems (17, 18,19). In another study the performance of gasohol in the three fleets totaling 108 vehicles from model years 1974 to 1981 was evaluated. Gasohol complaints were reported statistically higher than gasoline complaints with respect to starting, stalls, rough idle, hesitation, and loss of power (20).

The primary fuel related concern that occurs at elevated ambient temperatures is vapor lock. Vapor lock is caused by premature vaporization of fuel, impeding subsequent fuel supply to the cylinders. The vapor forming tendencies of gasolines have traditionally been described by the temperature at which V/L = 20 ($T_{v/l}$ =20). A gasoline with a high volatility has a low $T_{v/l}$ = 20. Since splash blended ethanol decreases $T_{v/l}$ = 20, it suggests that it will tend to increase the incidence of vapor lock. Increasing the ethanol concentration beyond 10 vol% will also lower the temperature for V/L ratio of 20, and thus may increase the likelihood of vapor lock. The wide variety of existing fuel system types, and their diverse responses to blends, suggest that additional research is needed to establish the most meaningful predictors of blend performance at high operating temperatures.

4.3 Enleanment Effect of Ethanol

Gasolines are mixtures of many hydrocarbon compounds that consist solely of hydrogen and carbon. Ethanol contains hydrogen, carbon, and oxygen. The exact air-to-fuel ratio needed for complete combustion of the fuel to carbon dioxide and water is called its “stoichiometric air-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 fuel and because some of the hydrocarbons have been displaced. For example, a blend containing 10% ethanol would only require 14.0 to 14.1 pounds of air per pound of fuel. The effect of this type of fuel change on an engine is called “enleanment”.

The air-fuel ratio is an important factor in the design of engines and fuel metering controls. Most automobile made after 1981in the U.S. and from mid 1980s in Canada use 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-fuel ratio. These vehicles have adjustment ranges that accommodate oxygenated fuels and, when operating in the “closed loop” mode, do not experience any effects from oxygenated fuel. During cold start and at full throttle, these systems operate in an “open loop” mode that provides a rich fuel mixture that is necessary for these conditions. In the rich mixture, “open loop” mode, vehicles do experience enleanment effects from the oxygenated fuel.

The driveability characteristics of the vehicle are not normally affected by switching between oxygenated and non-oxygenated gasolines, whether or not a vehicle is using a “closed loop” fuel control system. In a situation where a vehicle is not properly tuned and is operating in a “too lean" condition, switching to a fuel with increased oxygen would increase the risk of a driveability problem. The symptom most likely to appear in this situation is a hesitation during acceleration.

4.4 Effect of Ethanol on Fuel Economy

The differences in the heating values between gasoline and ethanol, as shown in Table 8, would result in a theoretical decrease in fuel economy for ethanol/gasoline blends in the 2% to 3% range when compared to gasoline.

Table 8
Theoretically Expected Effect of Ethanol on Fuel Energy *

Weight % Oxygen	Volume % Ethanol	Volume % Gasoline	Energy of 1 gal of fuel, Btu/gal	% Reduction Compared to Gasoline
0	0	100.0	114,000	-
2.0	5.7	94.3	111,834	1.9
2.7	7.7	92.3	111,074	2.6
3.5	10.0	90.0	110,200	3.3

- Heating value of Ethanol is taken as 76,000 Btu/gal

Because of its higher hydrogen to carbon ratio, ethanol produces a greater volume of gases per unit of energy burned than gasoline. This leads to higher mean cylinder pressures and more work performed during the expansion stroke. Ethanol also has a much higher heat of vaporization than gasoline. As the liquid fuel evaporates in the air stream being charged to the engine, a high heat of vaporization cools the air, allowing more mass to be drawn into the cylinder. This increases the power produced from a given engine size.

Therefore, when burned in a gasoline-optimized engine, ethanol/gasoline blends will produce an increase in the volume of combustion products, and the effect of charge-air cooling. The combined effect of these will result in an efficiency increase of about 1 to 2 percent. Hence the overall fuel economy reduction for E10 is expected to be very small compared to gasoline.

4.5 Water Solubility/ 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 at, or near, the bottom of their fuel tank, engines will not run once the water phase separates.

Non-oxygenated gasolines 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 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 (21). If phase separation were to occur, the ethanol/water mixture would be drawn into the engine and the engine would most likely stop.

Some vehicle manufacturers have expressed concern that 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. Based on the prolonged experience of using 10% ethanol/gasoline blends, the blends are no more susceptible to phase separation than non-oxygenated gasolines.

4.6 Material Compatibility

Some materials used in fuel systems tend to degrade over time, such as elastomers used to make hoses and valves. Other fuel system components are made of metals and plastics and must be compatible with the expected range of fuel composition. Some older elastomers were found to deteriorate more rapidly in the presence of alcohol. However, since mid-1980s, all vehicles have used fluoroelastomers, which are specifically designed to handle all modern gasolines, including ethanol/gasoline blends.

Permeation of fuel through elastomers can accelerate deterioration. In general, ethanol blends have higher permeation rates through elastomers than non-oxygenated gasoline. However, the higher permeation rates of ethanol blends are well within safety limits and are not expected to cause performance, deterioration, or safety problems. The experience of using ethanol blends in areas covered by the oxygenated gasoline program in the U.S. has not registered higher rates of materials degradation or failure than areas using conventional gasolines.

5. EFFECT OF ETHANOL/GASOLINE BLENDS ON EMISSIONS

Exhaust emissions from motor vehicles are very sensitive to changes in the air-fuel ratio as shown in Figure 7. The data indicate that air-fuel ratios slightly leaner than stoichiometric ($\lambda>1$) produce maximum emissions of oxides of nitrogen (NOx) and minimum emissions of hydrocarbons (HC). The response curve for carbon monoxide (CO) remains at a minimum value for mixtures leaner than stoichiometric. Thus ethanol/gasoline blends can be expected to reduce CO, and to a lesser extent HC emissions, due to mixture enleanment in open-loop vehicles calibrated to operate richer than stoichiometric on gasoline. This benefit of lower CO and HC, however, could be offset by increase in NOx. However, at part throttle, low load conditions, the response curve for NOx is not as pronounced as illustrated in Figure 7, and the NOx emissions under these conditions may not be greatly affected due to enleanment by blends.

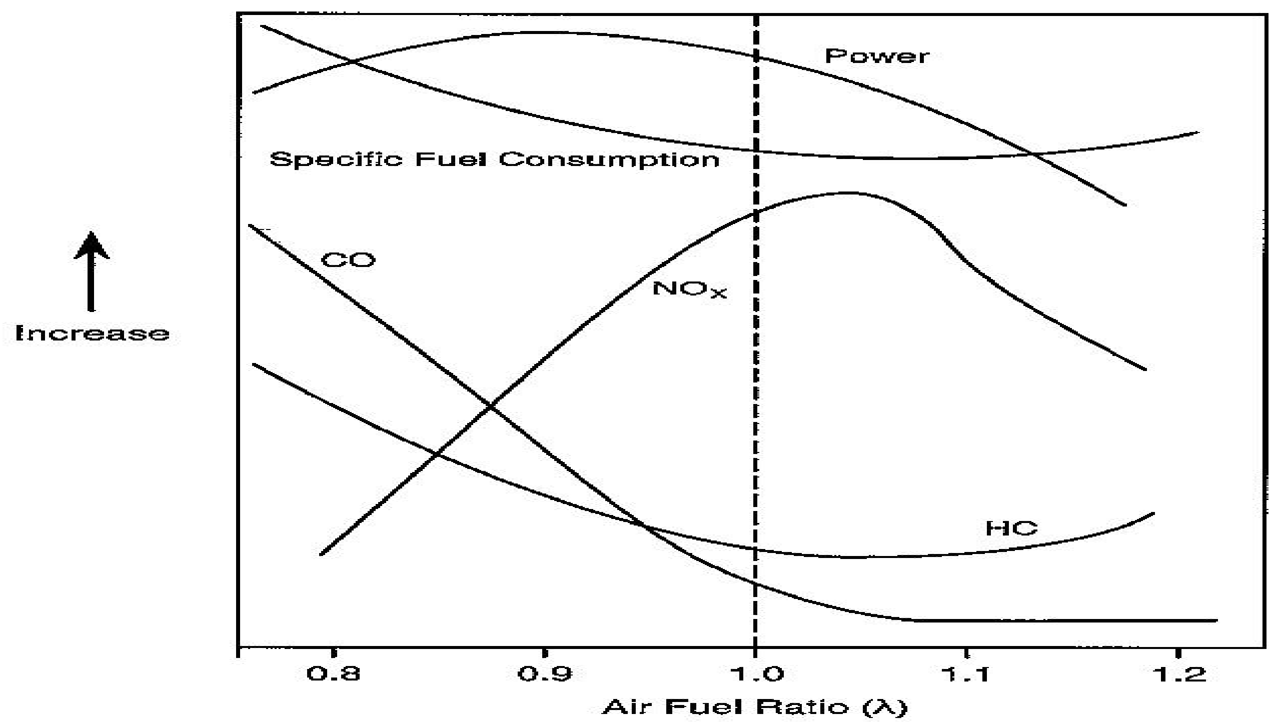

Figure 7 Effect of Air-Fuel Ratio on Exhaust Emissions

Fuel metering systems that have feedback closed-loop control are designed to maintain engine operation at stoichiometric mixtures under most driving conditions. These systems are deactivated during cold start, initial warm-up, and maximum power. Hence under these conditions the fuel metering systems operate in an open-loop mode. Some newer closed-loop vehicles are equipped with “adaptive learning”. Properly functioning vehicles with adaptive learning continuously adjust their open-loop fuel calibrations based on the most recent period of closed-loop operation. Thus, they can compensate for fuel-caused enleanment even during open-loop operation.

Both in the U.S. and Canada, gasoline vehicle emissions are regulated for the exhaust (CO, HC, and NOx) and evaporative (HC) emissions. The exhaust from vehicles operating on gasoline commonly contains a spectrum of partially oxidized HC species known as aldehydes. Aldehydes are photochemically reactive and can cause eye and mucous membrane irritation. They are also suspected carcinogens. Emissions of aldehydes in exhaust are not regulated and they form a very small fraction of total HC emission. Ethanol/gasoline blends directly or indirectly change the emissions characteristics of a vehicle designed for gasoline.

The oxygenates approved for use in blends by EPA, as compounds of hydrogen, carbon, and oxygen, are expected to have desirable emissions features as automotive fuels. The EPA has expressed concerns in two areas in its consideration of waiver requests for the use of ethanol in unleaded gasolines: a) increased evaporative emissions of hydrocarbons due to increase in fuel volatility by splash blending of ethanol, and b) increased exhaust emissions of NOx and aldehydes.

5.1 Evaporative Emissions

Gasoline vapors can be emitted from vehicles during engine shutdown through vents in the fuel tank and carburetor, and fuel delivery system from the intake of the engine air cleaner. Since the early 1970s the key technology employed to control evaporative emissions has been the charcoal packed canister connected to the vents in the fuel system. The charcoal readily absorbs vapors of gasoline hydrocarbons and alcohols generated during vehicle shutdown and retains the absorbed material until it can be purged with fresh air. The purged vapors are burned in the engine during vehicle operation.

The working capacity of the canister is established for each vehicle design by the manufacturer. If the canister becomes saturated, any additional vapor is forced through the air-intake port of the canister into the atmosphere, a condition known as “breakthrough”.

The addition of ethanol to gasoline has two effects on volatility that increase evaporative emissions: a) the increase in vapor pressure due to splash blending, and b) the depression of the distillation curve. These effects have already been discussed in Section 4 of this document. Work done by the CRC and many other investigators has documented that diurnal emissions increase with increased RVP, and hot soak emissions correlate well with RVP in combination with some factor of ASTM distillation (18,22). All EPA waivers except the gasohol waiver established the requirement that oxygenates could be used in blends only if the finished blend met the volatility criteria of ASTM D 439.

5.2 Exhaust Emissions

A vehicle may have a different exhaust emissions characteristics when operating on ethanol/gasoline blend instead of gasoline primarily because of a shift in the air-fuel ratio, and due the presence of ethanol in the fuel. Numerous studies have been conducted to quantify the effects of fuel oxygenates on vehicle emissions. The most useful available data is from dynamometer studies using the Federal Test Procedure (FTP).

The FTP studies have certain limitations:

a) A relatively small number of vehicles are tested and these may not be representative of the on-road fleet,
b) The studies with the best controls on fuel composition, such as the Auto/Oil AQIRP studies, do not necessarily represent the effect of the fuels sold to the consumers, and
c) The FTP test cycle may not necessarily represent real urban driving conditions.

In spite of these limitations FTP data is the best source of information on the fuel effects on vehicle emissions.

Based on the results of eleven test programs, the effects of oxygenated blends on exhaust emissions are summarized below (8, 23, 24, 25). It should be noted that some of these studies include oxygenates other than ethanol.

- Ethanol/gasoline blends reduced CO and HC emissions. Vehicles with newer technology: fuel injected, closed-loop, adaptive learning, three-way catalysts, show smaller reductions compared to vehicles with older technology: carbureted, oxidation catalyst, and malfunctioning high emitters.
- The effect of blends on NOx emissions was mixed, the response ranged from an increase of 0.47 grams per mile to a reduction of 0.43 grams per mile.
- The emissions of ethanol, based on CRC study (17), were found to be 0.0065 gram ethanol per mile. This value represents a very small fraction of the total hydrocarbons in the exhaust.
- Ethanol blends decreased vehicle emissions of the toxics, benzene and 1,3-butadiene.
- Acetaldehyde emissions were higher from ethanol blends compared to gasoline. However, three-way catalysts are quite efficient in minimizing aldehyde emissions.

Most of the available data on the effects of oxygenates on emissions is based on the fuels containing up to 10 volume percent ethanol (oxygen content of about 3.5% by weight). In one study conducted at EPA (26), six in-use vehicles were tested on base gasoline and nine ethanol/gasoline blends ranging from 10 to 40 percent ethanol by volume, to determine the effect of ethanol content in fuels on automotive exhaust emissions and fuel economy. The effect of ethanol content on vehicle performance was not investigated. For the majority of vehicles, total HC, and CO exhaust emissions as well as fuel economy decreased while NOx and acetaldehyde exhaust emissions increased as the ethanol content in the test fuel increased. Formaldehyde and CO2 emissions were relatively unaffected by the addition of ethanol.

The emissions benefits of oxygenates in gasoline are generally not linear with the amount of oxygen in the fuel. Hence the effects of increasing the ethanol content beyond 10 percent on exhaust and evaporative emissions on modern gasoline vehicles are not fully known. The octane enhancement benefit and the dilution effect on sulfur, olefins, and aromatics in gasoline with increasing ethanol content will certainly be positive.

6. VIEWS OF MOTOR VEHICLE MANUFACTURERS

6.1 World-Wide Fuel Charter

In a show of unity, the world's three automobile associations, on June 4, 1998, unveiled their "World-Wide Fuel Charter", intended to achieve consistent worldwide fuel quality (27). The charter is the result of two years of effort between the American Automobile Manufacturers Association (AAMA), Association des Constructeurs Europeens d'Automobiles (ACEA), and the Japan Automobile Manufacturers Association (JAMA).

The charter proposes three gasoline quality categories, ranging in stringency, which take into consideration customer requirements in a variety of markets and functional limitations of emission control technologies. The suggested specifications and other details for the three types of gasolines proposed in the charter are given in Appendix B.

"Category 1" gasoline, with 5 vol% benzene, 1000 ppm sulfur, and 50 vol% aromatics, is intended for use in areas requiring little in the way of vehicle emission control. The maximum oxygen content limit is 3.7 wt% where ethanol is allowed under existing regulations. For other oxygenates the limit is 2.7 wt%. Use of methanol is not permitted.

"Category 2" gasoline, which would be used in areas requiring advanced emission controls (for example, US Tier 0 or Tier 1, EU-Stage 2 or equivalent emission levels), proposes cutting sulfur to 200 ppm, benzene to 2.5 vol%, aromatics to 40 vol% and sets an olefin cap at 20 vol%. The general limit on oxygen content is 2.7 wt% , it can go up to 3.7 wt% where ethanol is allowed under existing regulations.

"Category 3" gasoline would be required in areas with most stringent emission control requirements such as California LEV, ULEV and EU-Stage 3 and 4 or equivalent emission levels. It sets maximum levels for sulfur at 30 ppm, benzene at 1 vo%, olefins at 10 vol%, aromatics at 35 vol%, and oxygenates at 2.7 wt% oxygen content.

Oxygenates, except methanol, would be allowed up to the set maximum limits in all categories under the charter proposal.

So far the reactions to the charter have varied from approval to concern. Comments were solicited through September 3, 1998. The petroleum industries in the U.S. and Canada are still working on their responses and comments to the charter.

6.2 Response on Telephone Interviews

Telephone interviews were conducted with three big U.S. automobile manufacturers, namely, General Motors, Ford, and Chrysler, as well as with some of the major international auto companies (Honda, Toyota, Volks Wagon etc.).

All three U.S. companies referred to the recently announced World Fuel Charter, suggesting that their preferred fuel for the U.S. and Canada would be gasoline of “Category 3”, in which they are trying to limit the oxygen content to a maximum of 2.7 weight percent (about 7.7 vol% ethanol). All three expressed concerns about the effect of ethanol on distillation curve and RVP and its subsequent detrimental effect on driveability, specially hot weather performance and vapor lock. The representatives of these companies generally agreed that although they do not have vehicle performance and emissions data on gasoline containing higher than 10 volume percent ethanol, they suspect that higher levels of ethanol would be undesirable. One manufacturer also raised concerns about the material compatibility problem with higher than 10 percent ethanol blends.

The views of the European and Japanese automobile companies were some what different. It was mentioned that their vehicles can operate on higher than 10 volume percent ethanol blends without any adverse effect on vehicle components. If they know the range of variation of fuels, it is also possible to tune their fuel systems to accommodate for such variations. The problem perceived by these companies was that if ethanol concentrations in gasoline blends are raised, then it would result in broadening the range of oxygen in gasoline in the vehicle fuel tanks. Based on their experience, it is well known that wider range of fuel oxygen content makes the precise control of air-fuel ratio more difficult. Hence, their future low emission vehicles would encounter driveability problems and may not be able to meet the stringent emission control requirements.

7. VIEWS OF PETROLEUM INDUSTRY

During the start of lead phase down in 1980s, the petroleum refiners in the U.S. and Canada made a number of changes and additional investment in their refineries to increase their octane capacity. They also started big marketing efforts for premium high octane unleaded gasolines. It should be mentioned that refiners have a much bigger profit margin on premium grade gasoline than regular gasoline. It is true that ethanol increases the octane rating of gasoline, but at the same time it reduces the share of petroleum component in gasoline. Many petroleum companies view it as a threat to their sales volume and market share. In 1994, EPA's proposal suggesting a mandate that 30% of RFG oxygen requirements should come from renewable components was defeated due to the strong opposition by the petroleum industry.

7.1 Response on Telephone Interviews

Telephone interviews were conducted with all major petroleum companies in Canada including, Petro Canada, Imperial Oil, Shell, Sunoco, and the CPPI. Many fuel ethanol retailers in Canada, such as Mohawk, MacEwen, and UPI Inc., were also approached for their views. It should be pointed out that the extent of feedback from these telephone communications ranged widely depending upon the interest of the company and the knowledge of their main technical person.

Some of the major oil companies expressed the views that they always market the fuels which satisfy the needs of consumers and meet the specifications of automobile manufacturers. A few of them mentioned about the "World-Wide Fuel Charter" put forward by the automobile manufacturers. It was also mentioned that increasing the ethanol content beyond 10 volume percent may cause vehicle performance problems, specially hot driveability and vapor lock. Two companies expressed concerns about the federal and provincial tax incentives which are being offered to ethanol. It was mentioned that in an open market situations without tax incentives, the oil industry will not mind increased ethanol levels in gasoline blends, if it met the performance criteria of automotive industry.

Most of the ethanol retailers in Canada have limited knowledge about the effect of ethanol concentration in ethanol/gasoline blends on vehicle performance and emissions. Their main interest is to sell ethanol/gasoline blends at ethanol levels which are economically viable. As shown in Table 4, many retailers still use ethanol at less than 10 volume percent in their blends. MacEwans sells its E10 with a (R+M)/2 of 89, at the price of regular gasoline which has an octane of 87.

8. VIEWS OF GOVERNMENT DEPARTMENTS AND OTHER ORGANIZATIONS

Many federal government departments in Canada, including the Department of Natural Resources, Agriculture Canada, Transport Canada, and Industry Canada were approached for their views on this issue. The provincial governments contacted include Ontario, British Columbia, Manitoba, and Saskatchewan. The agencies and companies approached in the U.S. included, EPA, Department of Energy, California Air Resources Board, Coordinated Research Council (CRC), Society of Automotive Engineers (SAE), Southwest Research Institute (SwRI), and ARCO. The views of other organizations such as Canadian Renewable Fuels Association, Ontario Corn Growers' Association, Commercial Alcohols, and Iogen Corporation were also solicited.

8.1 Response on Telephone Interviews

In the United States, currently there is no interest to increase the ethanol levels, in the so called low level ethanol/gasoline blends, beyond 10 volume percent. The study undertaken by the U.S. Department of Energy (4), on expanding the use of ethanol in transportation sector proposed that ethanol up to 17 volume percent can be used in ethanol/gasoline blends without any adverse or noticeable effect on vehicle performance. However, the views of automobile manufacturers were not sought in making this conclusion. Since then, another study has been conducted at the Oak Ridge National Laboratory in the U.S., and a draft report entitled, "Ethanol Demand in Gasoline Production", has been prepared (28). This study analyzes the competition for ethanol from gasoline and other oxygenates and identifies the future opportunities for fuel ethanol use in the U.S. Again, it is assumed that ethanol level in blends can be raised to 17 vol% (6 wt% oxygen) without adversely affecting the performance of modern gasoline vehicles. This assumption was based only on one reference (26), and the views of the automobile industry specially on vehicle performance were not sought.

The current views of most of the agencies in the U.S. are that because of the EPA waiver requirements, and the general direction of very tight air-fuel ratio control for future low emission gasoline vehicles, any effort to increase the ethanol content in blends beyond 10 percent will not get support from petroleum and automotive industries. Even the ethanol industry does not see any merit in pursuing this initiative because they have enough market for ethanol within the existing regulatory and fiscal framework as E10 in gasoline vehicles and near neat fuel in flesi fuel vehicles and heavy duty dedicated ethanol engines. The lack of research activities at CRC, SwRI, and SAE in this area supports the above findings.

The Canadian ethanol industry and related Industry Associations are happy with the current federal and provincial tax incentives for ethanol. They do not see any merit in increasing the ethanol content in ethanol/gasoline blends beyond 10 volume percent. In their analysis, any increase of ethanol content in gasoline blends will put added tax burden on the governments and result in loss of revenue based on each liter of fuel, which may not be in the interest of ethanol industry in the long run.

The representatives of various federal government departments and some of the provinces who were contacted by telephone, do not have strong views on this issue. In general, the federal departments do not support any policy initiative which may result in additional loss of tax revenue. The majority of representatives were not familiar with the vehicle performance and emissions issues related to ethanol/gasoline blends. Generally, the comments from provinces were non substantive. For example, the provinces of British Columbia and Saskatchewan do not offer any tax incentive for ethanol/gasoline blends. Hence ethanol retailers in these provinces are only getting the federal excise tax rebate on ethanol, which is not enough to make ethanol economically attractive in comparison with gasoline. Therefore, increasing ethanol content in blends will be of no interest. In addition, both these provinces are currently not implementing the CGSB volatility specifications for ethanol/gasoline blends.

In the United States, DOE and NREL (National Renewable Fuels Laboratory) are supporting programs to encourage the commercialization of ethanol production from cellulose. Similar efforts are also underway in Canada by Iogen Corporation. The communications with Iogen suggest that it will take 2 to 3 years to have a fully operational pilot plant for producing ethanol from cellulose. Researchers expect that production cost of ethanol from cellulose will be much lower than ethanol produced from corn or other food crops. If it happens, then larger volumes of ethanol would be available at lower cost, which would make ethanol more competitive to gasoline without the government support.

The greenhouse gas emissions of cellulosic ethanol compared to ethanol produced from agricultural feedstocks are lower due to the reduced use of fertilizers, pesticides, tillage and labor.

9. SYNTHESIS OF TELEPHONE RESPOSES, SUMMARY AND RECOMMENDATIONS

- None of the stakeholders involved in the use of ethanol/gasoline blends in current technology gasoline vehicles support the notion of increasing the ethanol levels beyond 10 volume percent. The future low emission and ultra-low emission gasoline vehicles, besides using new emission control technologies, will heavily rely on precise air-fuel ratio control. Hence, there is a general trend to minimize the range of oxygen content in gasoline. Increasing the ethanol content in ethanol/gasoline blends, in actual consumer use scenario, would tend to increase the range of oxygen content in the vehicle fuel tanks. This view is strongly supported by the "World-Wide Fuel Charter".

- The majority of automobile manufacturers are apprehensive about the effect of ethanol on vehicle performance and hot driveability. Although there is lack of hard data to support their anxiety, their views are based on the extrapolation of their experience using 10% ethanol blends. Hence automotive industry would not support the use of ethanol in blends greater than 10 vol%.

- The petroleum industry views ethanol as a threat to their gasoline market share and is unhappy about government tax incentives to ethanol. Hence, the majority of refiners would not support any initiative which may increase the use of ethanol as a transportation fuel.

- On the regulatory side, ethanol blends beyond 10 vol% will have to go through a very long and costly waiver approval process with the U.S. EPA. No industry or Industry Association in the U.S. is interested in pursuing this path. As a matter of fact, ethanol industry is quite happy with the current regulatory and fiscal framework and views a good market for fuel ethanol, as E10 in gasoline vehicles and as neat ethanol in flexi fuel vehicles and heavy duty dedicated engines. The Canadian ethanol industry has similar views. Therefore any move in Canada, independent of the U.S., to push this initiative may not get much support.

- There is no doubt that the use of biomass or cellulose based ethanol offers a net reduction in greenhouse gas emissions. However, overall greenhouse gas reduction benefits are directly proportional to the total amount of ethanol use, irrespective of the levels of ethanol in gasoline blends. In view of the extremely small volumes of current and future biomass based ethanol production in Canada, when larger volumes of ethanol can be produced from cellulose at a cheaper cost, there would be plenty of room for increasing the use of ethanol through 10 vol% ethanol/gasoline blends.

- In the long run, to play a major role in the transportation sector, ethanol would have to compete in the market place without government tax incentives. Hence a technological breakthrough in the production of ethanol from cellulose at a much cheaper cost is essential for the future of fuel ethanol.

10. DISCUSSION AND RECOMMENDATIONS

It is important to note that EPA's approval of gasohol waiver in 1978 was a political and policy decision. The limit of 10 volume percent ethanol in gasohol was not based on elaborate emissions testing and vehicle performance data. In fact many automobile manufacturers during the 1980s raised their concerns about poor vehicle driveability and adverse effect of ethanol on vehicle components. Since the 1980s, vehicle technology has greatly improved and most vehicle manufacturers have accepted the use of 10 percent ethanol blends. The modern automobiles are essentially insensitive to the type and amount of oxygenates in gasoline (29, 30)

In a recently published report entitled, "Scenarios of U.S. Carbon Reductions", the Interlaboratory Working Group (31) identified ethanol, especially cellulosic based ethanol, as having the greatest promise for reducing the greenhouse gas emissions from the transportation sector. There is also a growing interest in emissions trading and exchanging credits for greenhouse gases. It is possible that future government policies may recognize some form of greenhouse gas credits for ethanol which may subsequently replace the existing fuel tax incentives to ethanol. It would most likely promote the use of ethanol in the transportation sector.

The main advantage of using higher than 10% blends is to increase the use of ethanol in gasoline vehicles without making major efforts to improve the infrastructure for ethanol fueling stations or distribution system. Ethanol would thus replace larger volumes of gasoline in the transportation sector and contribute to reduction in greenhouse gas emissions. In order to accomplish it, the following steps would be necessary:

a) Obtain vehicle performance and emissions data on higher than 10% blends. Ethanol levels of 15 to 17 volume percent would be a good starting point.

b) If the vehicle performance and emissions results justify the use of higher than 10% blends, get the support of automotive and petroleum industries. In view of the present positions of these industries, it may not be an easy task.

c) Assess the possibility whether higher than 10% ethanol blends can be used in Canada, irrespective of their status in the U.S.

d) Support ethanol production from cellulose to produce larger volumes of ethanol at lower cost.

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APPENDIX A - Questionnaire on Ethanol / Gasoline Blends Study

1. What are your views on the use of Ethanol / Gasoline Blends in conventional gasoline vehicles / future low emissions vehicles.

Superior fuel
No difference
Inferior than conventional gasoline

2. In your opinion which are the most important attributes of Ethanol / Gasoline Blends as transportation fuel.

Higher octane advantage
Dilution effect on gasoline components such as sulfur, aromatics, and olefins
Gasoline antifreeze
Emissions benefits
GHG benefits
Energy self sufficiency

3. In view of the positive attributes of using Ethanol / Gasoline Blends, do you agree that it would be beneficial to maximize the amount of Ethanol in gasoline, beyond the current limit of 10 percent by volume while maintaining acceptable vehicle performance.

4. If Ethanol was available at a lower price than gasoline, will it alter your views anout using higher level Ethanol / Gasoline Blends.

5. If you do not support the use of Ethanol / Gasoline Blends, what are your main concerns.

Appendix B - World-Wide Fuel Charter

Introduction

The objective of the global fuels harmonization effort is to develop common, worldwide recommendations for "quality fuels," taking into consideration customer requirements and vehicle emissions technologies, which will in turn benefit our customers and all other affected parties.

Development of these common recommendations will ensure that automotive manufacturers provide consistent fuel quality advice, worldwide, to improve the auto industry's credibility in dialogues with government and the oil industry.

Implementation of the recommendations will:

Reduce the impact of motor vehicles on environment through reduced vehicle fleet emissions; Consistently satisfy customer performance expectations; and

Minimize vehicle equipment complexities with optimized fuels for each emissions control category, which will reduce customer costs (purchase and operation) and increase satisfaction

Three difference categories of fuel quality have been established for both unleaded gasoline and diesel fuel. These are described below.

Category 1: Markets with no or minimal requirements for emission controls, based primarily on fundamental vehicle/engine performance concerns.

Category 2: Markets with stringent requirements for emission control.

For example, markets requiring US Tier 0 or Tier 1, EU-Stage 2, or equivalent emission levels.

Category 3: Markets with advanced requirements for emissions control,

For example, markets requiring California LEV, ULEV and EU-Stage ¾, or equivalent emission level

To meet customer, environmental and energy challenges, the automotive industry is exploring advanced propulsion technologies worldwide. Category 3 has been defined to be those requirements needed by advanced technologies as they exist today. It is anticipated that additional categories of petroleum-derived fuels, including gasoline and diesel fuel, will be established in the future as engines and emission control technologies evolve in response to these challenges.

These fuel recommendations have been developed by the following organizations.

American Automobile Manufacturers (AAMA) - Chrysler Corporation, Ford Motor Company, General Motors Corporation

Association des Constructeurs Europeens d'Automobiles (ACEA) - BMW AG (Rover), DAF NV, Fiat Auto SPA (Iveco), Ford of Europe, Inc., General Motors Europe AG, MAN Nulzfohrzeuge AG, Daimler-Benz AG, Porsche AG, PSA Peugeot Citroen, Renault, Rolls-Royce Motor Cars Ltd, Scania AB, Volkswagen AG, Volvo AB

Japan Automobile Manufacturers Association (JAMA) - Daihatsu Motor Co., Ltd., Fuji Heavy Industries Ltd., Hills Motors, Ltd,, Honda Motor Co., Ltd., Isuzu Motors Limited, Kawasaki Heavy Industries, Ltd., Mazda Motor Corporation, Mitsubishi Motors Corporation, Nissan Diesel Motors Co., Ltd., Nissan Motor Co., Ltd., Suzuki Motor Corporation, Toyota Motor Corporation, Yamaha Motor Co., Ltd.

Category 1 Unleaded gasoline

Markets with nor or minimal requirements for emissions control; based primarily on fundamental vehicle / engine performance concerns.

Properties		Units	Limits	
			Min.	Max.
"91 RON" (1)	Research Octane Number	--	91.0	--
	Motor Octane Number	--	82.0	--
"95 RON" (1)	Research Octane Number	--	95.0	--
	Motor Octane Number	--	85.0	
"98 RON" (1)	Research Octane Number	--	98.0	--
	Motor Octane Number	--	88.0	--
Oxidation Stability		minutes	360	--
Sulfur Content		% m/m	--	0.10 (2)
Lead Content		g/l	--	0.013 (3)
Manganese Content		g/l	--	-- (3)
Oxygen Content		%m/m	--	2.7 (4)
Aromatics Content		% v/v	--	50.0
Benzene Content		% v/v	--	5.0
Volatility			See attached table, page 6	
Unwashed gums		mg/100 ml	--	70
Washed gums		mg/100 ml	--	5
Density		kg/m^3	625	780
Copper corrosion		merit	Class 1	
Appearance			Clear and bright	
Carburetor cleanliness		merit	8.0 (5)	--
Fuel injector cleanliness		% flow loss	--	10 (5)
Intake valve cleanliness		merit	9.0 (5)	--

General Notes:

N.B. #1: Additives must be compatible with engine oils. Addition of ash forming components is not allowed.

N.B. #2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc…)

Footnotes:

(1): Adequate labeling of pumps must be defined and used ; fuel should be dispensed through nozzles meeting SAE J285, "Recommended Practice Gasoline Dispenser Nozzle Spouts."

(2): Lower sulfur content preferred for catalyst equipped vehicles.

(3): No intentional addition.

(4): Up to 3.7 mass percent oxygen where ethanol is allowed under existing regulations. Methanol is not permitted.

(5): Compliance to this requirement can be demonstrated by the use of proper detergent additives in comparable base gasolines.

Variences for Leaded Gasoline, where legally permitted.

Properties	Units	Limits	
		Min.	Max.
Lead content, leaded gasoline	g/l	0.05 (1)	0.40 (2)

Footnotes:

(1): Only necessary to protect older vehicles with soft valves seats

(2): Lead content should be minimised where feasible.

Category 2   Unleaded gasoline

Markets with stringent requirements for emission control.

Properties		Units	Limits Min.	Limits Max.
"91 RON" (1)	Research Octane Number	--	91.0	--
	Motor Octane Number	--	82.0	--
"95 RON" (1)	Research Octane Number	--	95.0	--
	Motor Octane Number	--	85.0	
"98 RON" (1)	Research Octane Number	--	98.0	--
	Motor Octane Number	--	88.0	--
Oxidation Stability		minutes	480	--
Sulfur Content		% m/m	--	0.02
Lead Content		g/l	Non-detectable (2)	
Phosphorous Content		g/l	Non-detectable (2)	
Manganese Content		g/l	Non-detectable (2)	
Silicon		g/kg	Non-detectable (2)	
Oxygen Content		% m/m	--	2.7 (3)
Olefins Content		% v/v	--	20.0
Aromatics Content		% v/v		40.0
Benzene Content		% v/v	--	2.5
Volatility			See attached table, page 6	
Sediment		mg/l	--	1
Unwashed gums		mg/100 ml	--	70
Washed gums		mg 100/ml	--	5
Density		kg/m^3	715	770
Copper corrosion		merit	Class 1	
Appearance			Clear and bright	
Fuel injector cleanliness		% flow loss	--	5
Intake valve sticking		pass/fail	Pass	
Intake valve cleanliness				
Method 1 (CEC F-05-A94), or		mg/valve	--	50
Method 2 (ASTM D5500), or		mg/valve	--	100
Method 3 (proposed ASTM)		mg/valve	--	90
Combustion Chamber Deposits			TBD	

General Notes:

N.B. #1: Additives must be compatible with engine oils. Addition of ash forming components is not allowed.

N.B. #2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc…)

Footnotes:

(1): Adequate labeling of pumps must be defined and used ; fuel should be dispensed through nozzles meeting SAE J285, "Recommended Practice Gasoline Dispenser Nozzle Spouts."

(2): No intentional addition.

(4): Up to 3.7 mass percent oxygen where ethanol is allowed under existing regulations. Methanol is not permitted.

Category 3 Unleaded gasoline

Markets with advanced requirements for emission control.

Properties		Units	Limits	
			Min.	Max.
"91 RON" (1)	Research Octane Number	--	91.0	--
	Motor Octane Number	--	82.0	--
"95 RON" (1)	Research Octane Number	--	95.0	--
	Motor Octane Number	--	85.0	
"98 RON" (1)	Research Octane Number	--	98.0	--
	Motor Octane Number	--	88.0	--
Oxidation Stability		minutes	480	--
Sulfur Content		% m/m	--	0.003 (2)
Lead Content		g/l	Non-detectable (3)	
Phosphorous Content		g/l	Non-detectable (3)	
Manganese Content		g/l	Non-detectable (3)	
Silicon		g/kg	Non-detectable (3)	
Oxygen Content		% m/m	-- (4a)	2.7 (4b)
Olefins Content		% v/v	--	10.0
Aromatics Content		% v/v	--	35.0
Benzene Content		% v/v	--	1.0
Volatility			See attached table, page 6	
Sediment		mg/l	--	1
Unwashed gums		mg/100 ml	--	30
Washed gums		mg 100/ml	--	5
Density		kg/m^3	715	770
Copper corrosion		merit	Class 1	
Appearance			Clear and bright	
Fuel injector cleanliness		% flow loss	--	5
Intake valve sticking		pass/fail	Pass	
Intake valve cleanliness				
Method 1 (CEC F-05-A94), or		mg/valve	--	50
Method 2 (ASTM D5500), or		mg/valve	--	100
Method 3 (proposed ASTM)		mg/valve	--	90
Combustion Chamber Deposits			TBD	
Exhaust-valve sticking			TBD	

General Notes:

N.B. #1: Additives must be compatible with engine oils (no increase in engine sludge/varnish deposits). Addition of ash forming components is not allowed.

N.B. #2: Good housekeeping practices to reduce contamination (dust, water, other fuels, etc…)

Footnotes:

(1): Adequate labeling of pumps must be defined and used ; fuel should be dispensed through nozzles meeting SAE J285, "Recommended Practice Gasoline Dispenser Nozzle Spouts."

(2): Fuels meeting California Regulation Title 13, CCR Section 2262.2, including this enforcement system, are deemed acceptable.

(3): No intentional addition.

(4a): Fuel without oxygenated is preferred.

(4b): Where oxygenates are used, only ethers, including ethers derived from renewable sources, may be used. Methanol is not allowed.

Test Methods Gasoline

Properties	Units	ISO	ASTM	JIS	Other
Research Octane number	--	5164-90	D 2699-86	K 2280-96	
Motor octane number	--	5163-90	D 2700-86	K 2280-96	
Oxidation stability	minutes	7536-94	D 525-95	K 2287-96	
Sulfur content	% m/m	4260-87	D 2622-94	K 2541-96	
Lead content	g/l		D 3234-90	K 2255-95	EN 237-96
Phosphorous content	g/l		D 3231-94		
Manganese content	g/l		D 3831-94		
Silicon methods with	g/kg				ICP-AES (reference in-house detection limit = 1 ppm)
Oxygen content	% m/m		D 4815-94		
Olefins content	% v/v	3837-93	D 1319-95	K 2536-96	see footnote
Aromatics content	% v/v	3837-93	D 1319-95	K 2536-96	see footnote
Benzene content	% v/v		D 4420-94	K 2536-96	EN 238-96
Volatility - Rvp			D 5191-96	k 2258-87	
Distillation: E70/T10/T50/T90/FBP/residue		3405-88	D 86-96	K 2254-90	
Driveability Index					(1.5 x T10) + (3x T50) + T90 + (11 x 0_2 [wt%]) using ^{o}C
Sediment	mg/l		D 5452-97		
Unwashed gums	mg/100 ml	6246-95	D 381-94	K 2261-92	Replace with CCD test when available
Washed gums	mg/100 ml	6246-95	D 381-94	K 2261-92	
Density	kg/m^3	3675-93	D 4052-96	K 2261-92	ISO 12185
Copper corrosion	merit	2160-85	D 130-94	K 2249-95	
Appearance				K 2513-91	Visual inspection
Carburetor cleanliness	merit				
Intake valve sticking	pass/fail				CEC F-03-T-81
Intake valve cleanliness I	merit				CEC F-16-T-96
Intake valve cleanliness Ford 2.3L	mg/valve		D 6201-98		CEC F-04-A-87
Intake valve cleanliness (BMW test)	mg/valve		D 5500-97		
Intake valve cleanliness II (4 valve ave.)	mg/valve				
Exhaust valve sticking					CEC F-05-A-93
Fuel injector cleanliness	% flow loss		D 5598-95		CEC (PF 026) TBA
Combustion chamber deposits					CEC F-20-T96 / Ford TGA method / JASO method

Footnotes:
These methods are used in legal documents; more precise methods are available and may be used.