Environmental and Performance Effects of Ethanol Use

CHAPTER 3

The Twin Cities metropolitan area is required by federal law to use oxygenated gasoline from October through January.

The 1990 amendments to the federal Clean Air Act require wintertime use of oxygenated gasoline in 39 carbon monoxide (CO) non-attainment areas across the nation. These are areas where EPA air quality standards had not been met in the late 1980s. In Minnesota, the 10 county Twin Cities metropolitan area is a federally designated carbon monoxide non-attainment area. The Twin Cities is the only CO non-attainment area in the midwest.

The law also requires year-round use of reformulated gasoline (RFG) which contains a lower concentration of oxygenates in 9 severe ozone non-attainment areas. Minnesota does not have any ozone non-attainment areas, although a large part of the eastern seaboard from Maine to Virginia, much of California, and metropolitan areas closer to Minnesota including Chicago and Milwaukee are so classified. Both carbon monoxide and smog, which is produced by ozone and other pollutants, cause health problems, especially among people with respiratory or cardiovascular disease.[1]

Ethanol is one of two oxygenates commonly in use. The federal and state laws governing wintertime oxygenate use in Minnesota require a concentration of 2.7 percent oxygen (by weight), but they do not require the use of a particular compound. The requirement can be met with about a 7.7 percent mixture of ethanol (by volume) in gasoline. A 10 percent mixture of ethanol yields 3.5 percent oxygen content. Data from the Minnesota Department of Public Service shows that gasoline samples taken over the last several years actually contain an average of about 3.2 percent oxygen which corresponds to about 9.1 percent ethanol by volume. For economic reasons, ethanol is the only oxygenate currently used in Minnesota, although ethanol constitutes less than a third of the oxygenates used nationally.

While incentives for ethanol production and use are designed primarily as economic development programs, the federal oxygenated fuel program is designed to reduce pollution and improve human health. The Minnesota program that extends the federal oxygenated gasoline requirement both in time and geographic coverage has implications for the economic health of the industry, but also needs to be evaluated in terms of environmental, health, and performance effects. Toward this end, we addressed the following questions:

1 A few areas are out of attainment for both CO and ozone. Also, starting in June 1996, the entire state of California is required to use its own reformulated gasoline that is similar to the Federal Phase II fuel that is due to replace Federal Phase I reformulated gasoline in 2000.

Minnesota law will require the use of oxygenated gasoline statewide and year round starting October 1997.

- **Has wintertime ethanol use allowed Minnesota to meet federal carbon monoxide standards? Does the use of oxygenated fuel lower tailpipe emissions and atmospheric CO levels?**

- **Are there environmental benefits from summertime use of ethanol?**

- **Are there significant health effects of ethanol use?**

- **Does ethanol affect engine mechanical performance or fuel economy?**

In order to study the environmental benefits of ethanol use in Minnesota, we reviewed the literature and previous analyses of the impact of oxygenated gasoline on ambient CO concentrations. We interviewed officials in charge of the air quality program at the Minnesota Pollution Control Agency (PCA), and reviewed research sponsored by PCA. We also interviewed the Director of Atmospheric Modeling in the Environmental Protection Agency's Office of Mobile Sources. While federal requirements remain for wintertime use of oxygenated gasoline in CO non-attainment areas, according to EPA there are few violations of the EPA carbon monoxide standard nationwide, and there is a growing belief that the standards could be achieved in most places without the use of oxygenated gasoline.

CARBON MONOXIDE ABATEMENT

About 70 percent of CO emissions are produced by highway vehicles, according to the Minnesota Pollution Control Agency (PCA). The United States Environmental Protection Agency (EPA) regulates carbon monoxide concentrations through its National Ambient Air Quality Standards, and the Duluth and Twin Cities areas were judged to be out of compliance on the basis of measurements made in 1988-89 when initial measurements were taken.[2]

Oxygenated gasoline is designed to help lower the concentration of carbon monoxide in the atmosphere.

Requiring the use of oxygenated gasoline in winter months is part of a multifaceted strategy for reducing CO. Minnesota and some other states also check tailpipe emissions during annual vehicle inspections. Transportation planners seek improvements in traffic flow that can lower CO levels in problem areas. Finally, modernization of the automobile fleet has a positive effect, since newer cars with oxygen sensors and computerized fuel injection emit less CO than the vehicles they replace.

Nationally and in Minnesota, ambient CO levels have been declining for many years. By 1990, when Congress established the oxygenated fuel program, CO emissions had already declined nationally to about 30 percent of their 1970 level. By 1995 they had declined even further, to about 20 percent of the 1970 level. These declines were achieved in spite of greatly increased vehicle miles traveled. There is considerable discussion in the literature and among scientists advising federal regulatory agencies about how much of this decline can be attributed to oxygenated gasoline versus the other strategies.

2 Duluth was subsequently classified as in attainment.

Our review of the literature and interviews with experts suggests:

- **Most of the reduction in atmospheric CO in recent years is due to improved vehicle emissions equipment. It is not clear that the use of oxygenated gasoline can be linked to a significant reduction in atmospheric carbon monoxide. Scientists say that little or no reduction in ambient CO levels can be expected from the use of oxygenated fuels in newer vehicles with properly operating vehicle emissions systems.**

Minnesota has not recorded violations of CO standards in recent years.

According to data reported by the Minnesota Pollution Control Agency (PCA), Minnesota has not recorded any violations of CO levels over the last several years. Air quality is monitored continuously at various places including busy traffic intersections that are known to be trouble spots. If CO readings exceed the state standard of 30 parts per million (ppm), or the federal standard of 35 ppm on an hourly basis, or 9 ppm on an eight hour basis, an "exceedence" is recorded. A "violation" is defined as two exceedences per year. In recent years, Minnesota has recorded occasional exceedences, but they have not occurred often enough to cause a violation of state or federal air quality standards for CO. The federal and state hourly standards have not been violated since 1984, and the 8 hour standards have not been violated since 1991.[3] According to the EPA, only a few violations have been recorded anywhere in the country in recent years.

Measurement of compliance with the national ambient air quality standards by the EPA involves the use of a predictive ambient air quality model as well as atmospheric measurement. The model considers the age of the vehicle fleet, miles driven, vehicle inspection, use of oxygenated fuel, and other factors. According to PCA, it is possible that we would meet EPA carbon monoxide standards without the use of oxygenated fuel, given the modernization of the vehicle fleet that has occurred since the last violations were recorded.

Two recent government-sponsored studies have been conducted that address questions about the efficacy and safety of oxygenated gasoline: a report by the White House Office of Science and Technology Policy (OSTP), and a review of the OSTP by the National Research Council.[4] The Office of Science and Technology Policy directed the preparation of an interagency report on the effects of oxygenated gasoline including toxicological and performance effects. This study was carried out by working groups comprised of technical and scientific experts form several federal agencies as well as representatives of state government industry and environmental groups. The preamble to the study describes it as "...a scientific state-of-understanding report of the fundamental basis and efficacy of the EPA's winter oxygenated gasoline program."[5]

3 Minnesota Pollution Control Agency, Minnesota Air: Air Quality and Emission Trends 1974-1994, Draft Report September 23, 1996.

4 National Research Council,*Toxicological and Performance Aspects of Oxygenated Motor Vehicle Fuels*, (Washington, D. C.: National Academy Press, 1996.)

5 National Research Council, 152.

While the interagency report was intended to include a full risk assessment and cost-benefit analysis of oxygenated gasoline use, the Interagency Steering Committee guiding the research concluded that such an analysis was not possible in all areas because of research and data limitations. Where evidence was lacking, the report identified research that would allow a more thorough assessment of health and environmental effects. A draft of this report was issued for review in March 1996, but it has not yet been published except for its preamble and executive summary which appear in the National Research Council report.[6]

The National Research Council published a review of scientific studies of oxygenated fuel in 1996.

We have used the published summary of the original report and the National Research Council review to gain a sense of whether a national scientific consensus exists on the beneficial or harmful effects of oxygenated gasoline, specifically the effectiveness of oxygenated gasoline in reducing ambient carbon monoxide. The focus of the Interagency Report and the National Research Council review is on use of oxygenates in winter to reduce atmospheric carbon monoxide, not on summertime use of a lower level of oxygenates in reformulated gasoline which is required in ozone non-attainment areas. We will discuss summertime use of oxygenates later, since Minnesota has enacted a statewide year-round mandate for oxygenated gasoline, and there are different issues involved in warm-weather use of ethanol.

The draft Office of Science and Technology Policy report and the National Research Council both point to the reductions in ambient CO concentrations over 20 years and agree that vehicle emission controls have been a major factor in the reduction. Cars now carry one or two oxygen sensors that measure the oxygen content of the exhaust and adjust the engine to achieve complete combustion of fuel. The National Research Council report notes the weaknesses of data on the amount of the reduction that can be attributed to oxygenated fuels. It points out that the predictive EPA ambient air quality model currently in use overestimates the oxygenated fuel effect on CO emission reductions by a factor of two and calls for further study.[7] Because of improved pollution control equipment on newer vehicles, the report concludes:

> "For current and future vehicles,...only small changes in CO and NOx (Nitrous Oxide) emissions can be expected when using oxygenated fuels."[8]

Further, the report says:

> "...the federal (Interagency) report should better characterize the uncertainty about the extent to which oxygenated fuels have contributed to this reduction. The com-

6 The National Research Council was organized by the National Academy of Sciences in 1916, and has become the principal operating agency of the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The National Academy of Sciences is a private, non-profit research organization, chartered by congress in 1863 with a mandate to advise the federal government on scientific and technical matters. While the NRC is not infallible, its committees are composed of leading experts and its reports are considered quite authoritative. It is often called on to review evidence in situations where conflicting research results are introduced into the policy debate.

7 National Research Council, 4.

8 National Research Council, 31.

> mittee believes that it has not been established that oxygenated fuels have been a major factor in this reduction."[9]

The National Research Council found a lack of scientific evidence on the oxygenated fuel program's effectiveness.

Thus, while wintertime use of oxygenated fuels enables Minnesota to meet technical air quality standards, there is a surprising amount of uncertainty about the efficacy of oxygenated gasoline for reducing ambient CO levels.

The uncertainty over the efficacy of oxygenated gasoline goes beyond its effectiveness relative to other abatement strategies, it concerns the limitations of laboratory and on-road tests of vehicles and fleets for predicting real-world changes in tailpipe emissions. The CO data in the interagency report were largely collected using the Federal Test Procedure that specifies an ambient temperature of 75 degrees Fahrenheit. Until 1994, EPA test procedures collected CO emissions data only at 75 degrees, even though the federal CO oxygenated fuels program involves wintertime regulations and requires wintertime use of oxygenated gasoline. The interagency report reviewed some research data taken at 35 degrees and 50 degrees, but high emitting vehicles were not included in these tests, and high emitting vehicles are largely responsible for the atmospheric CO problem. The 1990 Clean Air Act called for model year 1994 and later vehicles to be tested at 20 degrees as well as 75 degrees. CO emissions data are lacking for temperatures less than 20 degrees for both dynamometer and on-road tests.

The National Research Council study says that the effect of oxygenated gasoline is different at temperatures below 20 degrees, and even points to some evidence of *increased* CO emissions with oxygenated fuels at these temperatures.[10] But the main point of the National Research Council's review of the evidence in both dynamometer studies, and on-road studies is the absence of reliable studies at a range of temperatures, using suitable experimental controls.[11]

Tests of oxygentated fuel at wintertime temperatures are lacking, even though the federal program is a wintertime requirement.

The National Research Council is extremely critical of the fact that a wintertime program does not involve tests at a greater range of winter temperatures. The limitations of the EPA test requirements are hard to understand given that CO emissions vary greatly with temperature, and are a problem mainly at low temperatures. The EPA and some defenders of the EPA test procedure point out that many of the CO non-attainment areas are in places with fairly warm winter temperatures.[12] It goes without saying that winter temperature tests are especially important to understand the effect of oxygenated gasoline in Minnesota and other northern states. The EPA staff we talked to acknowledged the lack of winter temperature tests and pointed out the difficulty of standardizing test procedures at a wider range of temperatures. They did not have an effective rebuttal of the NRC

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9 National Research Council, 49.

10 National Research Council, 35.

11 National Research Council, 37.

12 A letter to the Chair of the NRC Committee from University of California-Berkeley Professors Robert Harley, Civil and Environmental Engineering, and Robert Sawyer, Mechanical Engineering, is quoted in the August 16, 1996 *Ethanol Report* as defending 75 degree tests because "...nearly half of the non-attainment areas are in milder-winter locations where temperatures much below freezing are irrelevant."

criticism, however, and indicated that they would probably sponsor additional tests.

SUMMERTIME USE OF OXYGENATED FUEL

Ethanol increases the volatility of the fuel with which it is mixed. Evaporation causes harmful compounds in gasoline to be released into the atmosphere.

Minnesota will require oxygenated gasoline statewide starting in October 1997. There is a question in the scientific literature over the environmental benefits of summertime use of ethanol.[13] This question is of more than academic interest in Minnesota because of the requirement to use oxygenated gasoline year round. For this reason, we inquired about the summertime effects of ethanol use, and found:

- **The Minnesota Pollution Control Agency does not advocate summertime use of ethanol in order to reduce carbon monoxide. A study commissioned by PCA to address the question of whether summertime use of ethanol is harmful concludes that ethanol use is neither harmful nor beneficial.**

Gasoline is naturally more volatile during warm weather and, on top of this, gasoline mixed with ethanol is more volatile than straight gasoline. Evaporation causes harmful volatile organic compounds (VOCs) contained in gasoline to be released into the atmosphere. These VOCs along with oxides of nitrogen and carbon monoxide cause atmospheric ozone levels to increase.

Many parts of the country are designated as ozone non-attainment areas and are required to use "reformulated" gasoline in warm-weather months. The Twin Cities has an ozone problem, but not one that brings it to formal non-attainment status.[14] Even in areas where reformulated gasoline is not required, gasoline is required to have lower volatility in the summer than in the winter in order to work properly. Lower volatility is not the only specification that reformulated gasoline must meet, but it is responsible for most of its ability to reduce VOC emissions. About 13 percentage points of the 15 percent VOC reduction that reformulated gasoline is required to achieve come from lower volatility.

The use of ethanol in gasoline was the subject of controversial decisions by Congress and the EPA in the early 1990s. The 1990 Clean Air Act provided a one pound per square inch waiver, as measured by the Reid Vapor Pressure scale, for gasoline mixed with 10 percent ethanol. Ethanol would have been excluded from summertime use without the waiver for reasons presented above. MTBE, the other oxygenate in common use nationally, does not increase the volatility of gasoline and could have been used in the absence of the waiver. The waiver for ethanol was vigorously opposed by oil industry representatives, environmental groups, and some state government officials who wanted to enforce stricter state volatility standards, but a compromise was reached that permits ethanol's use.

13 Ethanol is the only oxygenate used in Minnesota according to Department of Public Service Division of Weights and Measures.

14 The Twin Cities ozone level would be in violation of existing California standards.

The Minnesota Pollution Control Agency (PCA) continues to advocate wintertime use of oxygenated gasoline, but says it has never advocated year-round use. Year-round use is, however, included in the contingency plan submitted to the EPA by Minnesota. (EPA requires state agencies to indicate additional steps they will take if atmospheric monitoring shows CO violations.) PCA says year-round use was included in the contingency plan only because Minnesota was already doing it

A study of summertime use of ethanol found it to be neither beneficial nor harmful.

In response to concerns about summertime use, PCA sponsored a study of the impact of year-round oxygenated fuel use in Minnesota.[15] Because Minnesota's levels are fairly close to applicable federal standards, Minnesota presumably cannot afford to increase the emission of organic compounds that produce ozone. Motor vehicles release fuel vapors from leaks and from venting of the fuel system. As noted, ethanol causes the fuel with which it is mixed to become more volatile and release volatile organic compounds which cause ozone readings to increase. Ethanol itself is not a problem; it is its effect on the volatility of gasoline which causes an increase in evaporative emissions.

The study found that a 10 percent ethanol mixture tends to increase evaporative VOC emissions while lowering exhaust emissions. The amounts of exhaust and evaporative emissions per mile vary according to driving speeds. The report estimates that the use of ethanol blends reduces summer ozone from zero to 3 percent, depending on the speed of the vehicle. The most favorable ratio is obtained at low or high speeds tested (20 MPH and 60 MPH) and the "worst case" measurements were at 30-50 MPH.

PCA does not argue that oxygenated fuel is needed to reduce CO levels outside the October through January period, but concludes from the Whitten study that ethanol does not cause additional pollution. PCA does not offer the study as definitive, however, and points out that reasonable scientists disagree about the effects of summertime ethanol use and ozone formation. The issue was supposed to be the focus of a National Academy of Sciences study this year, but this study has not been carried out. Further research sponsored by authoritative national scientific bodies that will illuminate or settle the issue is needed.

As matters stand, gasoline wholesalers and retailers sell gasoline with more ethanol in the warm weather months (between May 1 and September 15) than in the winter because federal regulations permit a one pound per square inch waiver from vapor pressure standards between May and mid-September. The waiver is not triggered, however, unless fuel mixtures contain 9 to 10 percent ethanol rather than lesser amounts that still would be sufficient to meet the 2.7 percent oxygenate requirement.[16] According to our calculations of data from the Minnesota Department of Public Service Weights and Measures Division, ethanol concentration was higher in the Twin Cities in the June 1 to August 8, 1996 period than the period February 1, 1996 to May 31, 1996. Ethanol was mixed at an average of 3.07 percent oxygen from January through May, and 3.36 percent oxygen from June to early August. We do not have data past August 8, 1996. (1996 was the first sum-

15 Whitten, Gary Z., Barbara S Austin, and Karina O'Connor, *Ozone Impact of Year-Round Oxy-Fuel Program In Minnesota*, Systems Applications International, June 30, 1994.

16 About 7.7 percent ethanol achieves the required 2.7 percent oxygen level.

mer period in which oxygenated fuel use was mandated. The warm weather months are the season when volatility is of greatest concern and ozone levels are highest.)

Summertime use of ethanol was made possible by a federal waiver of Clean Air Act requirements.

This waiver is a perverse response to complex environmental regulations at the state and federal levels and makes little sense in relation to either carbon monoxide or ozone abatement objectives. State law requires year-round use of oxygenated gasoline in the Twin Cities starting in 1996 and statewide starting October 1997. But the state requirements co-exist with a federal requirement to achieve a lower volatility of gasoline between May and September 15. Adding just 3 or 4 percent ethanol raises volatility enough to exceed the federal volatility standard of 9 pounds per square inch (on the Reid Vapor Pressure scale), but adding 9 to 10 percent ethanol qualifies the mixture for a one pound per square inch waiver of the federal requirement, so that the fuel can meet the vapor pressure standard at 10 pounds per square inch.

OTHER EFFECTS

Mandated use of oxygenated gasoline has engendered controversy around the country. There have been numerous complaints of adverse health effects, and adverse effects on fuel economy and mechanical operation. In this section we briefly examine the evidence on toxic effects of oxygenates on human health, and the effects of oxygenates on engine performance.

HEALTH EFFECTS

In recent years, many articles have been published on the health and performance effects of oxygenated gasoline in refereed scientific journals. In part these have been prompted by complaints of health effects by users of oxygenated gasoline, most of which is mixed with MTBE, not ethanol. Since the major reason for adding oxygenates to gasoline is concern about adverse health effects of CO and ozone levels in the atmosphere, the oxygenated gasoline needs to be as safe as non-oxygenated gasoline if the program is to be judged beneficial in terms of the purpose it was designed to serve. Agencies of the federal government have recently been active in reviewing the scientific evidence on the health effects of oxygenated gasoline.

The National Research Council reviewed a report by the Health Effects Institute (HEI) on the health effects of oxygenated fuels that was part of the Interagency report on oxygenated fuels discussed above. The HEI report says:

> "The potential health effects from exposure to gasoline containing MTBE include headaches, nausea, and sensory irritation in some, possibly sensitive, individuals based on reports after exposure to oxygenates..."[17]

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17 National Research Council, 126.

However the same report goes on to say:

> "Adding oxygenates is unlikely to substantially increase the health risks associated with fuel used in motor vehicles; hence, the potential health risks of oxygenates are not sufficient to warrant an immediate reduction in oxygenate use at this time. However, a number of important questions need to be answered if these substances are to continue in widespread use over the long term."[18]

There are no adverse health effects associated with the use of ethanol in gasoline.

Ethanol, of course, is widely ingested in alcoholic beverages, and there are adverse health effects noted in the literature, but none that are associated with the low levels of ethanol exposure that occurs as a consequence of its use as an automotive fuel.

Our conclusions as a result of a brief review of the human health issue are:

- **Low level exposure to ethanol is not associated with the same effects linked to MTBE, including nausea, headaches, and disorientation. The complaints of users of oxygenated fuel in states where MTBE is used have some scientific support.**

- **The national scientific bodies that have conducted major reviews of the evidence conclude that MTBE-containing fuels do not pose permanent health risks substantially different from those associated with nonoxygenated fuels.**

Concern about adverse health effects could conceivably undermine support for the use of oxygenated fuel, including ethanol, in the future even though the adverse health effects are associated with MTBE, not ethanol. Advocates of ethanol point out its advantages in this regard along with the fact that MTBE has an unpleasant odor while ethanol is essentially odorless.

CARBON DIOXIDE

Ethanol is a renewable fuel, and unlike fossil fuels, ethanol use does not add carbon dioxide (CO_2) to the atmosphere. Ethanol produces CO_2 when it burns but the corn or other raw material used to produce the ethanol had recently removed this CO_2 from the atmosphere. Greenhouse gasses such as CO_2 are associated with the threat of global warming. Ethanol is clean-burning compared to gasoline, and if pure ethanol were used as fuel it would not cause a variety of pollution problems caused by burning fossil fuels.

Ethanol would hold promise of significant environmental benefits if it could be used in substitution for a significant amount of gasoline, especially if it could be manufactured without using fossil fuel or other polluting processes. Currently, 95 percent of ethanol is produced from corn. Some environmental groups such as the Sierra Club and the Environmental Defense Fund are opposed to ethanol production from corn because of concern about adverse environmental effects. The Envi-

18 National Research Council, 127.

ronmental Defense Fund says that ethanol produced from corn increases greenhouse gas emissions 25 percent above gasoline because fossil fuels and nitrogen fertilizers are required to grow the corn.[19] The Sierra Club recommends that "...federal and state subsidies for gasohol from grains should be replaced by an energy conservation program of comparable magnitude."[20] In any case, a substantial amount of energy is used in ethanol production, and this is mostly fossil fuel used in growing corn, producing fertilizer, and distilling alcohol.

Ethanol accounts for one-tenth of one percent of U.S. energy consumption.

Still, assuming that ethanol use has a positive environmental benefit, it needs to be kept in mind that under any realistic scenario, ethanol will supply an extremely small fraction of U. S. annual energy consumption. In looking at the data, we found:

- **Ethanol's potential to contribute to the problem of atmospheric CO2 is extremely limited.**

Ethanol is quite a small fraction even of renewable energy. Ethanol accounts for 2 to 3 percent of total biomass energy consumed in the U. S. annually between 1990 and 1994. By far the largest biomass source is wood, which has supplied around 79 to 82 percent of biomass energy in recent years. However, as Table 3.1 shows, all biomass sources including ethanol, wood and waste supplied only a little over 3 percent of U. S. energy in the period 1990 to 1994. Ethanol itself supplied about one-tenth of 1 percent of U. S. energy compared to fossil fuels which supplied around 85 percent. In order to contribute meaningfully to a solution of the problem of CO2 accumulation in the atmosphere, ethanol has to substitute for fossil fuel. Not only does ethanol contribute very little to U. S. energy needs, it takes nearly three quarters of the energy contained in a gallon of ethanol to manufacture that amount.

Ethanol production at 1995 levels consumes close to 7 percent of the U. S. average corn crop in recent years. If national ethanol production were increased tenfold, ethanol would supply about 1 percent of U. S. energy needs, but take 70 percent of the U. S. corn crop. Long before this happened, food prices would have increased unacceptably, so in the absence of new production technology, this level of ethanol production is unlikely using corn or other high-value agricultural commodities. On the basis of this reasoning, we conclude that ethanol production from corn can have, at best, a very small effect on atmospheric accumulation of CO2.

FUEL ECONOMY AND PERFORMANCE EFFECTS

Ethanol has been widely used for more than a decade, and engines manufactured since the early 1980s are designed to use up to a 10 percent ethanol mix. Very few

19 Environmental Defense Fund Letter Vol. XXIII, No. 3 June 1991.

20 Sierra Club Policy Code 3.2.3, Adopted January 30-31, 1982.

Table 3.1: United States Energy Consumption by Energy Source, 1990-94

	Quadrillion BTUs					Percentage Distribution				
	1990	1991	1992	1993	1994	1990	1991	1992	1993	1994
RENEWABLE										
Biomass										
Wood	2.155	2.151	2.249	2.228	2.266	2.558%	2.560%	2.639%	2.561%	2.560%
Waste	0.395	0.426	0.460	0.468	0.488	0.469	0.507	0.540	0.538	0.551
Ethanol	0.082	0.065	0.079	0.088	0.098	0.097	0.077	0.093	0.101	0.111
Total Biomass	2.632	2.642	2.788	2.784	2.852	3.124	3.144	3.271	3.200	3.222
Solar Energy	0.067	0.068	0.068	0.069	0.069	0.080	0.081	0.080	0.079	0.078
Conventional Hydro	3.113	3.196	2.871	3.156	3.037	3.695	3.804	3.369	3.627	3.431
Geothermal	0.327	0.331	0.349	0.362	0.357	0.388	0.394	0.410	0.416	0.403
Wind Energy	0.024	0.027	0.030	0.031	0.036	0.028	0.032	0.035	0.036	0.041
Total Renewable	6.163	6.264	6.106	6.403	6.350	7.316%	7.455%	7.165%	7.359%	7.174%
FOSSIL FUELS										
Coal	19.101	18.770	18.868	19.430	19.541	22.674%	22.338%	22.140%	22.331%	22.076%
Coking Coal	0.005	0.009	0.027	0.017	0.024	0.006	0.011	0.032	0.020	0.027
Natural Gas	19.296	19.606	20.131	20.841	21.156	22.905	23.333	23.622	23.952	23.900
Petroleum	33.553	32.845	33.527	33.841	34.653	39.829	39.089	39.340	38.893	39.148
Total Fossil Fuels	71.955	71.231	72.553	74.129	75.373	85.414%	84.772%	85.133%	85.196%	85.150%
Nuclear Electric	6.161	6.579	6.607	6.519	6.830	7.313%	7.830%	7.753%	7.492%	7.716%
Hydroelectric Pumped	-0.036	-0.047	-0.043	-0.041	-0.035	-0.043	-0.056	-0.050	-0.047	-0.040
TOTAL ENERGY CONSUMPTION	84.243	84.027	85.223	87.010	88.518	100.000%	100.000%	100.000%	100.000%	100.000%

Source: United States Department of Energy, *Renewable Energy Annual, 1995*, Table 1.

manufacturers continue to complain about adverse effects of 10 percent blends in recently manufactured equipment. There are, of course, many complaints about mandatory use of ethanol and the limited availability of gasoline that does not contain ethanol.

Ethanol contains 33 percent less energy per gallon than gasoline; use of ethanol results in lower gas mileage.

Fuel Economy

Ethanol contains about 33 percent less energy per gallon than gasoline; therefore, the use of ethanol results in fewer miles per gallon. When ethanol is mixed at up to 10 percent, the effect is small enough that it is unlikely that individual consumers can detect a difference between gasohol and conventional gasoline, but the effect is big enough to be significant on a statewide basis.

At a theoretical level, miles per gallon is directly related to the energy content of fuel as measured in Btus.[21] The National Research Council concludes after reviewing 13 research studies: "There is agreement based on data from a wide variety of sources that if a given level of an oxygenate reduces the energy content per gallon of a formulated gasoline by 1.6 percent, for example, the expected reduction in fuel economy is also 1.6 percent."[22] We reviewed studies that cited a range of values for the energy content of conventional gasoline and ethanol. Table

21 One Btu (British Thermal Unit) is the amount of heat energy required to raise one pound of water one degree Fahrenheit.

22 National Research Council, 47.

3.2 also shows this information and also the energy content of oxygenated fuels made by blending gasoline with ethanol at specified rates. These calculations show a 2.3 to 3.5 percent decrease in the energy content of oxygenated fuels compared with conventional gasoline, depending on the blend. On the basis of these data, we expect:

- **There will be a 2.3 to 3.5 percent drop in fuel economy when motor vehicles are run on gasoline blended with ethanol.**

Table 3.2: Energy Content of Gasoline, Ethanol, and Ethanol Blends

	DAI, Inc.	GAO	USDA-ERS
Btu Content of Ethanol[1]	76,100	76,100	83,961
Btu Content of Gasoline	108,500-117,000[2]	114,000	1252,073
Energy Reduction with 7.7% Blend	2.3%-2.7%[2]	2.6%	2.53%
Energy Reduction with 10% Blend	3.0%-3.5%[2]	3.3%	3.29%

Source: Downstream Alternatives, Inc., *Changes in Gasoline III,* 1996 Update; U.S. General Accounting Office, 1996; U.S. Department of Agriculture.

[1]British Thermal Unit is a standard unit for measuring the quantity of heat energy equal to the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

[2]Lower numbers refer to higher-volatility, wintertime gasoline blends.

Effects of this magnitude are difficult to detect in ordinary driving. A vehicle that gets 25 miles per gallon would be expected, (assuming a 3.5 percent reduction in fuel economy), to get over 24 miles per gallon on oxygenated fuel. Variations of this magnitude can easily be caused by normal, tank-to-tank changes in driving conditions, traffic patterns, or fill levels when refueling.

Different engines respond differently to oxygenated fuels. Older engines, especially those without fuel injection and/or computer controls commonly are tuned to run slightly rich, that is, with a higher-than-necessary fuel to air ratio.[23] These vehicles may benefit from the extra oxygen carried by oxygenated fuel, and the reduction in fuel efficiency may be lessened or even reversed by more efficient combustion for these vehicles. Modern engines with computer controls are able to adjust to differing operating conditions and therefore optimize performance. These engines tend to experience the largest reductions in fuel economy from use of oxygenated fuels.

Although individuals are not likely to notice reduced fuel economy, these effects are significant at the state or national level. Moreover, Minnesota has a vehicle fleet that is, on the whole, newer than the national average. Considering the state's annual gasoline consumption of roughly 2 billion gallons, even a 2.3 percent fuel economy reduction requires the use of 46 million additional gallons of fuel. This amount should be considered when the cost of ethanol to consumers or ethanol's contribution to energy security are considered.

23 This is because the loss in performance is much greater for running too lean than too rich, and changes in temperature and atmospheric pressure change the amount of oxygen the engine can take in.

Mechanical Performance

Much of the legislative debate in recent years has focused on the fuel requirements of small engines, watercraft, and antique automobiles. In addition, there are claims and counterclaims concerning ethanol's contribution to fuel system problems in modern automobiles. It is beyond the scope of this report to present detailed findings on each of the reported problems in each type of engine application, but we did review the arguments and available literature. We found:

- **There is no substantial evidence of mechanical problems in modern engines from use of 10 percent ethanol blends, although in some instances engines need minor modification.**

This is not to say that the types of problems mentioned have not existed or do not exist. They may, however, be attributable to other factors such as ethanol blends in excess of 10 percent, use of methanol or other alcohols (used in the early 1980s), engines manufactured before the early 1980s, or operator errors.

Few engine performance problems are caused by oxygenates in gasoline.

Historical problems attributed to ethanol fuels in general are poorly documented, and often do not consider other sources of performance problems. Some of these problems pertain to equipment manufactured before the early 1980s, before the introduction of alcohol-resistant elastomers and plastic parts. Once such machines have been upgraded, problems relating to materials compatibility do not persist. Current research reviewed by the White House Office of Science and Technology Policy (OSTP) concluded, and the National Research Council concurred, that except for possible drivability problems due to enleanment, performance problems due solely to the presence of oxygenates in gasoline are not expected.

Enleanment is a potential problem only for certain types of engines. A few snowmobile manufacturers and makers of marine and recreational equipment recommend relatively minor modifications of carburetted engines to offset the enleanment effects of oxygenated gasoline. Overblending oxygenates in gasoline can add to this enleanment effect. Fixing the problem requires installing a shim kit and rejetting the carburetor and is estimated to cost about $100. Minnesota has over 254,000 registered snowmobiles, but most of these machines will not need modification.

SUMMARY

The Twin Cities area has not recorded any violations of national air quality standards since the wintertime use of oxygenated gasoline became mandatory. However, most of the reduction in ambient carbon monoxide levels is due to improved vehicle emissions equipment. State law will require year-round use of oxygenated gasoline starting in October 1997, however, state and federal pollution control officials do not argue that there are environmental benefits for summertime use of gasohol in Minnesota.

There are no adverse health effects associated with ethanol use as a fuel additive, although there are some concerns about another oxygenate, MTBE, but these are hard to distinguish from the effects of straight gasoline which also causes some health problems. Ethanol blends cause minor engine performance problems in some marine and recreational equipment with carburetted engines. From the perspective of statewide costs, the most significant factor is the reduction in fuel economy of 2.3 to 3.5 percent due to the lower energy content of ethanol compared to gasoline.