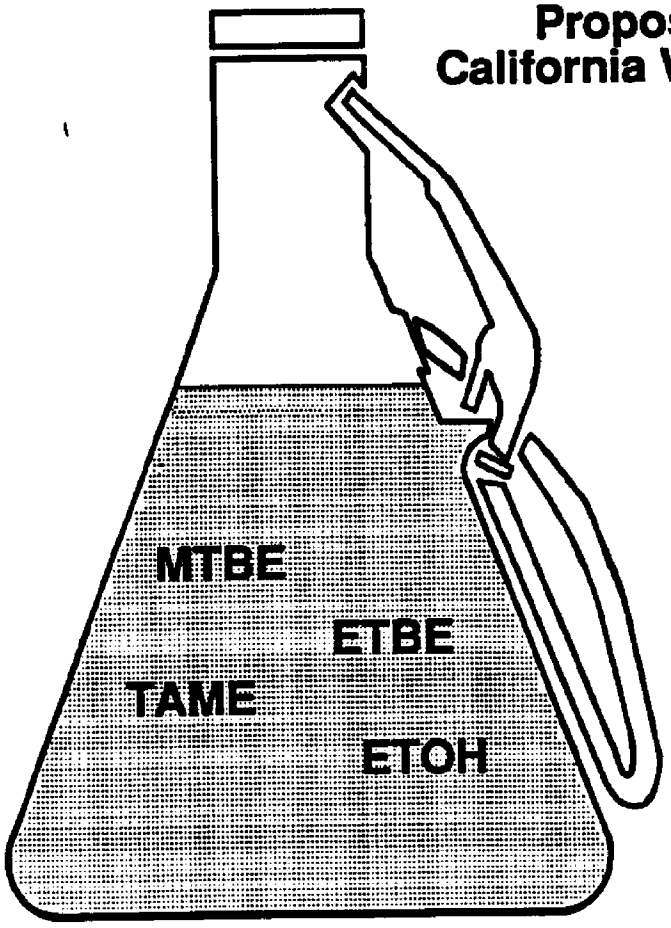
Gasoline
0146

California Air Resources Board

California Phase 2 Reformulated Gasoline Specifications

Volume 2
Proposed Regulation for California Wintertime Oxygenates Program

Staff Report



Release Date: October 4, 1991

State of California
Air Resources Board

State of California
AIR RESOURCES BOARD
Stationary Source Division

Initial Statement of Reasons

PUBLIC HEARING TO CONSIDER THE ADOPTION OF AND AMENDMENTS TO REGULATIONS REGARDING REFORMULATED GASOLINE (PHASE 2 GASOLINE SPECIFICATIONS), AND THE WINTERTIME OXYGEN CONTENT OF GASOLINE

VOLUME 2
PROPOSED REGULATION FOR CALIFORNIA WINTERTIME OXYGENATES PROGRAM

Date of Release: 10/4/91
Schedule for Consideration: 11/21/91

Location:

Auditorium
State Building
107 South Broadway, Room 1138
Los Angeles, CA

This report has been prepared by the staff of the California Air Resources Board and approved for publication. Approval does not signify that the content necessarily reflect the views and policies of the Air Resources Board, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

ACKNOWLEDGMENTS

This report was prepared with the assistance of the staff from other divisions at the Air Resources Board. In addition, we would like to acknowledge the cooperation of the Western States Petroleum Association and member companies, the automobile manufacturing companies, the American Independent Refiners Association and member companies, the California Renewable Fuels Council, and the U.S. Environmental Protection Agency. We would particularly like to thank:

Principal Authors

Jose Gomez
Bob Nguyen

Contributing Authors

Bill Riddell
Tuan Ngo

Clerical Support

Marline Hicks
Theresa Dade

Reviewed and Approved by:

Peter D. Venturini, Chief, Stationary Source Division
Ronald A. Friesen, Assistant Chief, Stationary Source Division
Dean C. Simeroth, Chief, Criteria Pollutants Branch
Gary M. Yee, Manager, Industrial Section

Table of Contents

Contents | Page

I. INTRODUCTION AND SUMMARY....1

A. FEDERAL CLEAN AIR ACT REQUIREMENTS....1
B. CALIFORNIA CLEAN AIR ACT REQUIREMENTS....2
C. PROPOSED CALIFORNIA WINTERTIME OXYGENATES GASOLINE PROGRAM....2
D. RECOMMENDATION....8

II. MOTOR VEHICLE EMISSIONS AND AIR QUALITY....9

A. EMISSIONS INVENTORY FROM GASOLINE FUELED VEHICLES....9
B. AMBIENT AIR QUALITY....9

III. EFFECTS OF OXYGENATES ON MOTOR VEHICLE EMISSIONS....17

A. OVERVIEW OF TEST PROGRAMS....17
B. EFFECTS OF OXYGENATES ON MOTOR VEHICLE EMISSIONS....18

IV. DISCUSSION OF PROPOSED CALIFORNIA WINTERTIME OXYGENATES GASOLINE PROGRAM....22

V. IMPACTS OF PROPOSED PROGRAM....26

A. AIR QUALITY AND EMISSIONS REDUCTIONS....26
B. ECONOMIC IMPACTS....26
C. ENVIRONMENTAL IMPACTS....27

REFERENCES

APPENDICES

A. PROPOSED REGULATION FOR CALIFORNIA WINTERTIME OXYGENATES PROGRAM
B. AIR QUALITY DATA
C. EMISSION IMPACTS
D. COSTS AND ENVIRONMENTAL IMPACTS

List of Figures

Figure		Page
Figure 1:	Area Designation for Federal and State Ambient Air Quality Standards	3
Figure 2:	Statewide CO Emissions	10
Figure 3:	Statewide VOC Emissions	10
Figure 4:	Statewide NOx Emissions	11
Figure 5:	PM10 Precursors	11
Figure 6:	Average Days the State Standards Were Exceeded	14
Figure 7:	RVP Control Period and Peak CO Season Months	15
Figure 8:	RVP Control Period and Peak CO Season Months	16
Figure 9:	CO Emissions Response	19
Figure 10:	NOx Emissions Response	21
Figure 11:	Reid Vapor Pressure Response	21

I.

INTRODUCTION AND SUMMARY

Presented below is a proposed California wintertime oxygenates gasoline program designed to satisfy the federal Clean Air Act requirements for areas that are nonattainment for the federal ambient air quality standard for carbon monoxide (CO). The proposed program will also contribute to attaining the state ambient air quality standard for CO in areas where the state standard is exceeded. The proposal is further designed to avoid wintertime increases in oxides of nitrogen emissions in California. In the discussion below the proposed California wintertime oxygenates gasoline program will frequently be referred to as the proposed program or program.

The proposed California wintertime oxygenates gasoline program sets standards for the oxygen content in gasoline sold in California during the winter months. Staff estimates that full implementation of the proposed program will reduce wintertime motor vehicle CO emissions by about 10 percent or approximately 1200 tons per day in 1992/93.

A. FEDERAL CLEAN AIR ACT REQUIREMENTS

The federal Clean Air Act (CAA) Amendments of 1990 created many new requirements for states that exceed the national ambient air quality standards. Specifically for CO, Section 211(m) of the CAA requires a state to revise its state implementation plan (SIP) and to implement an oxygenated gasoline program for those areas that are designated nonattainment for the federal CO standard beginning in the winter of 1992. This program is to be in effect during the portion of the year in which a nonattainment area is prone to high ambient concentrations of carbon monoxide. The CAA further requires that the program specify an average oxygen content of at least 2.7 percent by weight in gasoline, and a regulatory control period of not less than four months. The federal CAA however, allows a waiver for reducing the required oxygen content, if a state can demonstrate that the specified average oxygen content will interfere with the attainment of other national and state ambient air quality standards. A waiver to shorten the control period is also allowed, if a state can demonstrate that because of meteorological conditions a reduced period will assure that CO exceedances will not occur outside of the petitioned control period. Since the federal CO standard is exceeded during all the months identified as the control periods for California, a demonstration to reduce the control periods based on meteorological conditions is not possible.

The CAA also requires the Environmental Protection Agency (EPA) to develop guidelines for the development and implementation of the oxygenated

gasoline program as required by the CAA. The EPA has developed proposed guidelines and issued them for comment on September 6, 1991. The proposed guidelines were developed through a regulatory negotiation process which included the participation of industry, the public, and local, state and federal regulatory agencies (ARB staff participated in these negotiations). EPA intends to publish final guidelines by November 1991.

B. CALIFORNIA CLEAN AIR ACT REQUIREMENTS

The California Clean Air Act requires the Air Resources Board (ARB) to adopt and implement motor vehicle emission control programs to attain and maintain the state's ambient air quality standards. Specifically, section 43013 of the California Health and Safety Code (HSC) requires the ARB to adopt fuel specifications to reduce exhaust and evaporative emissions from motor vehicles. Also, section 43018 requires the ARB to adopt control measures which will result in the most cost effective combination of controls on all classes of motor vehicles and motor vehicle fuels, including but not limited to, all of the following:

- reductions in motor vehicle exhaust and evaporative emissions;
- reductions from in-use motor vehicles through improvements in emissions control system durability and performance;
- requiring the purchase of low-emission vehicles by state fleet operators; and
- specification of vehicular fuel composition.

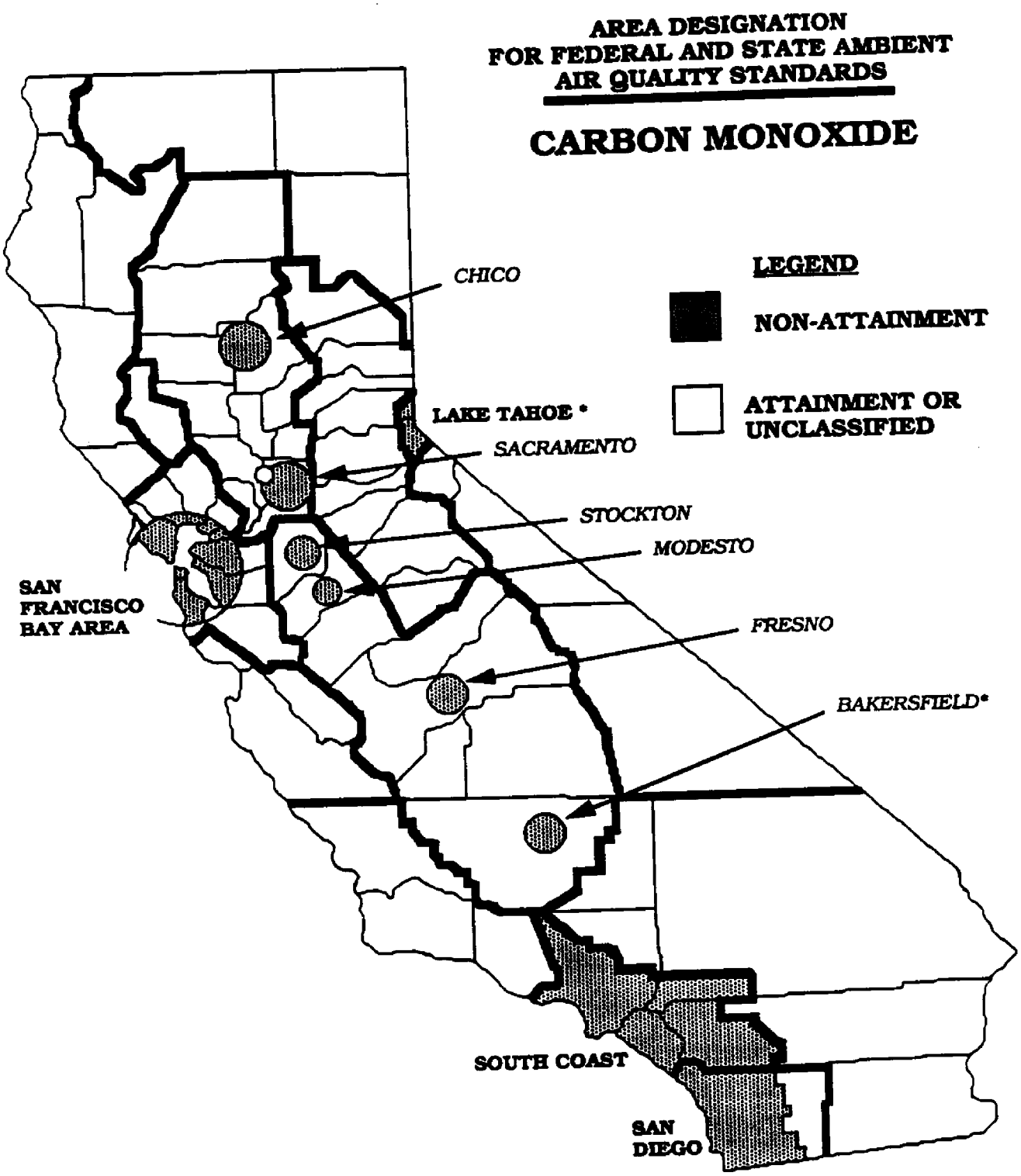
Implementation of the proposed program to reduce CO emissions during winter months will meet, in part, the requirements of the California Clean Air Act.

C. PROPOSED CALIFORNIA WINTERTIME OXYGENATES GASOLINE PROGRAM

1. Why is staff proposing a wintertime oxygenates gasoline program?

As discussed above, the federal Clean Air Act (CAA) Amendments of 1990 requires states, that have areas classified as nonattainment for the federal CO standard, to implement a wintertime oxygenated gasoline program in those areas. There are presently eight areas in California that are designated as nonattainment for the federal CO ambient air quality standard. With respect to the state standard, there are presently 11 areas within California that exceed the state's ambient air quality standard for CO. These nonattainment areas are contained within the federal nonattainment areas (see Figure 1), except for the areas of Sacramento, Lake Tahoe, and Bakersfield. For the Sacramento area, the state nonattainment designation applies to the entire county in comparison to the federal nonattainment designation, which applies only to the northern portion of the county. Lake Tahoe and Bakersfield are only nonattainment for the state standard. These CO nonattainment areas are

Figure 1



* Designated as non-attainment only for state ambient air quality standard.
Other areas are non-attainment for both state and federal ambient air quality standards

located throughout California which suggests that the proposed program be implemented on a statewide basis. The federal CAA requires that oxygenated gasoline requirements must be implemented by the winter of 1992/93. The California Clean Air Act requires that the nonattainment areas achieve compliance with the state CO standard as expeditiously as possible.

2. Why is staff proposing that the program be implemented statewide?

Carbon monoxide nonattainment areas are generally large population centers, which account for a large percentage of the total gasoline consumed in California. Of the 4.3 billion gallons of gasoline consumed statewide during the wintertime CO season (September through February), staff estimates that implementing the proposed program in only nonattainment areas will affect about 80 percent or approximately 3.5 billion gallons of the gasoline consumed in the winter. Thus, attainment areas within the state would account for about 20 percent or approximately 0.8 billion gallons of the gasoline consumed during the winter months.

Considering that the gasoline distribution system in California is regionally designed, the segregation of gasoline markets to meet the requirements of the proposed program would be difficult to implement for the small portion of unaffected gasoline and would pose both distribution and enforcement difficulties. Also, motor vehicle travel patterns are such that implementing the program only in the affected areas will not maximize the potential benefits, since vehicles incoming from attainment areas would contribute to the CO emissions in controlled areas. Staff considered these factors and others, and concluded that the proposed program should be implemented statewide to utilize the existing gasoline distribution system and maximize the CO reductions in nonattainment areas. Also, attainment areas would benefit from the proposed program through reduced emissions of CO to assure continued maintenance of the federal and state ambient air quality standards for CO.

3. What is the major requirement of the proposed program?

Staff is proposing that gasoline subject to the proposed program have a minimum oxygen content of 1.8 percent by weight and a maximum oxygen content of 2.2 percent. The oxygen limit is the same regardless of the type of oxygenate used (e.g., ethanol or methyl t-butyl ether). Based on available data, staff believe these limits will provide for substantial reductions in CO emissions while avoiding increases in oxides of nitrogen emissions that would occur if higher oxygen levels were allowed.

4. Why are the oxygen limits being proposed different than those specified in the federal Clean Air Act?

Staff is proposing limits that are different than the 2.7 percent by weight limit specified in the CAA because staff believe that the oxygen limit specified in the CAA will result in increases of oxides of nitrogen emissions from motor vehicles. These emission increases will adversely impact the attainment of federal and state ambient air quality standards for

ozone, PM10, and nitrogen dioxide (NO_2) all of which are exceeded during one or more of the winter months. Further, NOx emissions contribute to visibility reduction and to acid deposition. The federal CAA provides that the oxygen requirements may be adjusted or waived if the EPA Administrator determines that the use of gasoline with oxygenates would prevent or interfere with the attainment by an area of a national or a state ambient air quality standard other than CO.

The proposed oxygen limits are based on staff's evaluation of data from various motor vehicle test programs. These programs include EPA studies, Auto/Oil studies, a Radian study and an American Petroleum Institute (API) study.

In general, we believe that adding oxygenates to gasoline at levels that result in an oxygen content significantly exceeding 2 percent by weight will result in increases in NOx emissions. Staff estimate that by increasing the oxygen content from 2 percent to the federal specified average of 2.7 percent oxygen, NOx emissions can increase from 1 to 9 percent based on the type of oxygenate used. This compares to the potential gain in additional CO emission reductions of about 4 percent at the average 2.7 percent oxygen content. Limiting the addition of oxygenates to gasoline at levels that give a 2 percent by weight oxygen content still results in significant reductions in CO, a small reduction in emissions of volatile organic compounds (VOCs) and avoids increases in emissions of NOx.

It should be noted that data on the effect of oxygenates on NOx emissions is not totally consistent. Some data indicate that the NOx effect may be dependent to some extent on the type of oxygenate, while other data indicate that the oxygen content of the gasoline is the controlling factor. Staff is still evaluating data and expects to have the results of additional vehicle test programs to consider in the near future. If further evaluation indicates that adjustment to the proposed program is needed to optimize emissions reductions or to avoid adverse emissions impacts, staff will make such recommendations at the Board hearing.

5. <u>What months of the year will the proposed program be applicable?</u>

The proposed program will generally apply during those months of the year when CO violations occur. For the South Coast Air Basin, this is from September through February. Generally, for northern California, this is from October through January. Violations of the ozone and the PM10 ambient air quality standards also occur routinely during the months of September and October. In the South Coast Air Basin, violations of the nitrogen dioxide standard and ozone standards also occur during months when the CO standard is exceeded. Increases in emissions of VOCs or NOx will contribute to the violations of ozone, PM10, and NO_2 ambient air quality standards.

To reduce the evaporative emissions of VOCs, the state has established a program to limit the volatility of gasoline during the ozone season. This includes limiting the volatility of gasoline in September and October. The addition of some oxygenates (ethanol and methanol) increases the volatility

of gasoline and evaporative emissions. Also, the addition of oxygenates significantly above 2.0 percent oxygen by weight results in an increase in emissions of NOx. To prevent increases in emissions of NOx, staff proposes that for the months of September and October the maximum oxygen content be limited to 2.2 percent by weight. Staff also proposes to eliminate the minimum oxygen specification during the months of September and October. The elimination of the minimum oxygen content specification is needed because an oxygenate shortage is predicted in at least the early years. The shortage is created because ethanol can no longer be used during these months. Ethanol cannot be used as an oxygenate added to gasoline because it increases the volatility of gasoline and the resulting gasoline will be in violation of volatility limits that apply in these months. When adequate supplies of other oxygenates become available, the minimum of 1.8 percent can be restored.

6. What are other provisions of the proposed program?

The proposed program contains a variance provision under which a person unable to comply with the regulation can apply to the Executive Officer for a variance. As a result of the regulatory negotiated rule making process, EPA is recommending that states consider provisions to allow a refiner under extreme and unusual circumstances to distribute non-complying fuel, for a brief period of time. Staff believe that the proposed variance provision will meet EPA's suggested criteria. The regulation also specifies the test method that must be used to determine the oxygen content of gasoline.

7. What are the impacts of the staff proposal?

Implementing the proposed program will reduce CO emissions by about 10 percent (1200 tons/day) statewide beginning in 1992. In future years, the effectiveness remains approximately the same until the new low emission vehicle program impacts the make-up of the vehicle fleet. Emissions of VOCs would be reduced by about 3 percent, and we do not expect increases in NOx emissions. Staff estimates the cost effectiveness of the program to be about 50 cents per pound of CO reduced. The program will have an overall air quality benefit since CO emissions will be reduced in CO nonattainment areas as well as areas that are in attainment of federal and state CO standards. Reductions in CO emissions in attainment areas will provide further assurance against potential CO violations in the future. Staff believes that there will not be any adverse impacts on the supply of gasoline in California or on the availability of oxygenates. Staff has identified no adverse impacts on air quality or other environmental impacts.

8. What types of oxygenates are expected to be used to meet the proposed oxygen limit for gasoline?

The oxygenates that probably will be used are ethanol and methyl t-butyl ether (MTBE). For the 1992/93 control period, the projected production of ethanol and MTBE in California is estimated to be approximately 7 million gallons and 76 million gallons, respectively. Staff estimate that producers of gasoline in California will need to import about 60 million gallons per year of ethanol and about 270 million gallons per

year of MTBE. These numbers will change in the future as additional California production, especially for MTBE, becomes available.

Another factor that may influence the choice of oxygenates is the tax incentives available to producers and blenders of ethanol. Currently, two types of tax incentives are available. One is for ethanol added to gasoline at an amount that results in at least a 10 percent by volume ethanol content. A 10 percent ethanol blend qualifies for a 5.4 cents per gallon tax exemption against the federal motor vehicle fuel tax applied to gasoline. The other incentive is a tax credit given to blenders of ethanol into gasoline which allows the blenders to apply a tax credit of 54 cents per gallon of ethanol against their federal income tax. This is referred to as the "blender's tax credit". The proposed maximum oxygen content limit of 2.2 percent will prevent producers/blenders of gasoline from qualifying for the 5.4 cents per gallon federal motor vehicle fuel tax, however, the producers/blenders are still eligible to apply for the 54 cents per gallon "blender's tax credit".

9. Are oxygenates being used in today's gasolines?

The primary oxygenates being used in today's gasolines are MTBE and ethanol. MTBE is used primarily as an octane enhancer. Ethanol also has good octane qualities, however, it increases the vapor pressure of the gasoline blend, thus increasing evaporative emissions from vehicles. Use of ethanol is largely motivated by economics; namely the motor vehicle fuel tax exemption and income tax credit that is available to gasoline producers and blenders. About 5 percent of the gasoline consumed in California contains 10 percent ethanol (3.5 percent oxygen) and is commonly named gasohol.

10. Does the use of oxygenates in the summertime impact motor vehicle emissions?

The use of oxygenates affects motor vehicle exhaust and evaporative emissions during the summertime. Specifically, motor vehicle exhaust emissions of CO and VOCs are reduced, but emissions of NOx can increase at oxygen levels significantly greater than 2 percent by weight. The effect on VOC emissions is dependent on the type of oxygenate. Ethanol added to gasoline results in an increase in evaporative emissions from motor vehicles and in the storage and dispensing of gasoline. MTBE added to gasoline has no significant effect on the vapor pressure of gasoline. Both oxygenates result in some reductions of VOCs in motor vehicle exhaust. Staff are currently evaluating the need to limit, by regulation, oxygenate use during the summer months to avoid NOx increases. If appropriate, a regulation will be developed and brought before the Board for its consideration.

11. Are there other regulatory provisions regarding the use of oxygenates?

Currently, the California Health and Safety Code Section 43830 provides an exemption from the summertime Reid vapor pressure (RVP) requirements for gasoline which is blended with an ethanol content of greater than 10 percent by volume as long as the base gasoline meets the RVP limits. Additionally, the federal RVP requirements provides a 1 psi allowance for gasoline

containing at least 9 percent ethanol (40CFR 80.27(d). The federal CAA Amendments of 1990 also allow ethanol blends to exceed the 1 psi allowance if the base gasoline meets the RVP limits (federal CCA, section 211(k)(4)).

12. How does the proposed wintertime oxygenates gasoline program fit in with the proposed Phase 2 gasoline specifications?

The proposed regulation for the wintertime oxygenates gasoline program contains a sunset clause (section 2258(e)) which ends the program on December 31, 1995. However, portions of the wintertime oxygenates program have been incorporated into the proposed regulation for Phase 2 gasoline specifications which begins on January 1, 1996. Specifically, the minimum oxygen content of 1.8 percent and the maximum oxygen content of 2.2 percent for the wintertime regulatory control periods are part of the proposed Phase 2 wintertime specifications. In addition to this, the proposed Phase 2 regulation for oxygenates will apply year-round and on a statewide basis. The proposed regulation also allows alternative gasoline formulations (section 2266(c)) that comply with oxygenate limits between 1.8 percent and 2.7 percent oxygen content.

D. RECOMMENDATION

Staff recommends the Air Resources Board (ARB) adopt the proposed California Wintertime Oxygenates Gasoline Regulation contained in Appendix A and summarized above.

Staff also recommends that ARB petition the EPA for a waiver of the oxygen content levels specified in the CAA and contained in EPA's guidelines. Specifically, the petition will request:

1. California wintertime oxygen content in gasoline be limited to a range of 1.8 to 2.2 percent by weight instead of the federal CAA minimum average oxygen content of 2.7 percent by weight.

2. During those months when the summertime Reid vapor pressure control program overlaps with EPA's defined CO wintertime control periods, establish a cap of 2.2 percent by weight oxygen with no minimum to facilitate compliance with the RVP specification while ensuring that there is no increase in NOx emissions.

Finally, staff would prepare the necessary State Implementation Plan (SIP) revisions to submit to EPA to satisfy the federal CAA requirement for a wintertime oxygenated gasoline program by the winter of 1992.

II.

MOTOR VEHICLE EMISSIONS AND AIR QUALITY

Motor vehicles are a major source of pollutant emissions, including carbon monoxide (CO), volatile organic compounds (VOCs), and oxides of nitrogen (NOx). Also, emissions of VOC and NOx from motor vehicles act as precursors in the formation of ambient ozone and PM10. Over the past two decades, California has implemented aggressive motor vehicle control programs aimed at reducing emissions from both new and existing vehicles. However, motor vehicles continue to be a major source of air pollution. While past regulatory efforts have resulted in improved air quality, additional emission reductions are needed from motor vehicles to help attain the federal and state ambient air quality standards.

A. EMISSIONS INVENTORY FROM GASOLINE FUELED VEHICLES

Figure 2 through Figure 4 depict the contribution of gasoline fueled vehicles to the statewide inventory for CO, VOCs, and NOx. For 1987, on-road gasoline fueled vehicles contributed about 60 percent of the CO emissions from all sources. Gasoline fueled vehicles also contributed about 35 percent of the emissions of VOCs and 38 percent of the NOx emissions. For PM10 emissions, gasoline fueled vehicles only account for about 0.2 percent of the directly emitted PM10 inventory; however, they are a significant contributor of VOC and NOx emissions which are precursors to PM10 (Figure 5).

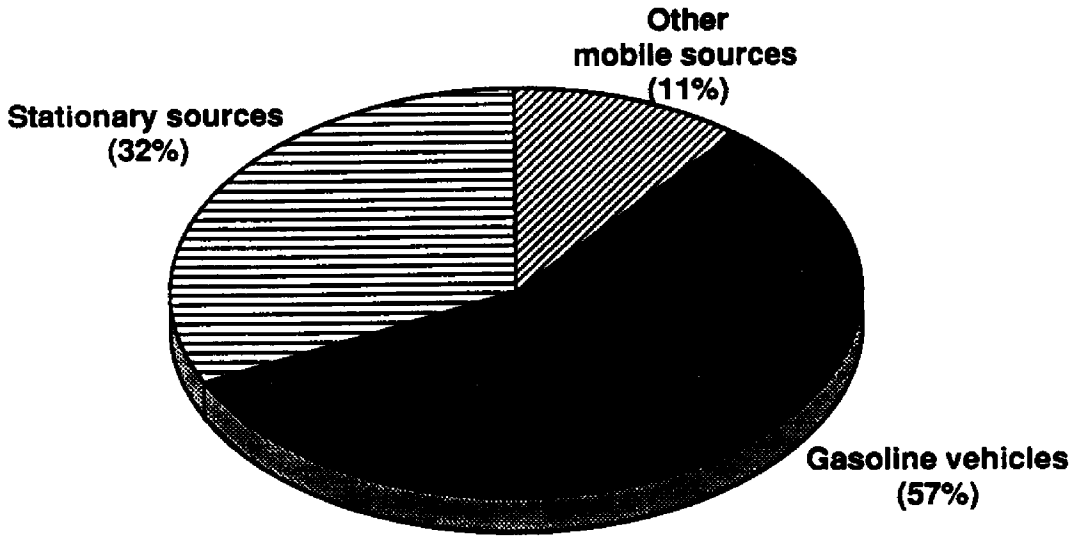
Carbon monoxide emissions from gasoline fueled vehicles are the dominant contributor to exceedances of the federal and state ambient air quality standards because most exceedances occur in areas of heavy vehicle activity. This continues to be true, in spite of the motor vehicle programs that have been developed and implemented in California over the last two decades.

B. AMBIENT AIR QUALITY

The federal and state ambient air quality standards are exceeded in many areas of California; especially in highly populated areas where motor vehicle use is high. Exceedances of ozone and PM10 can occur throughout the year while nitrogen dioxide (NO_2) and CO exceedances are more concentrated during the winter months.

Figure 2

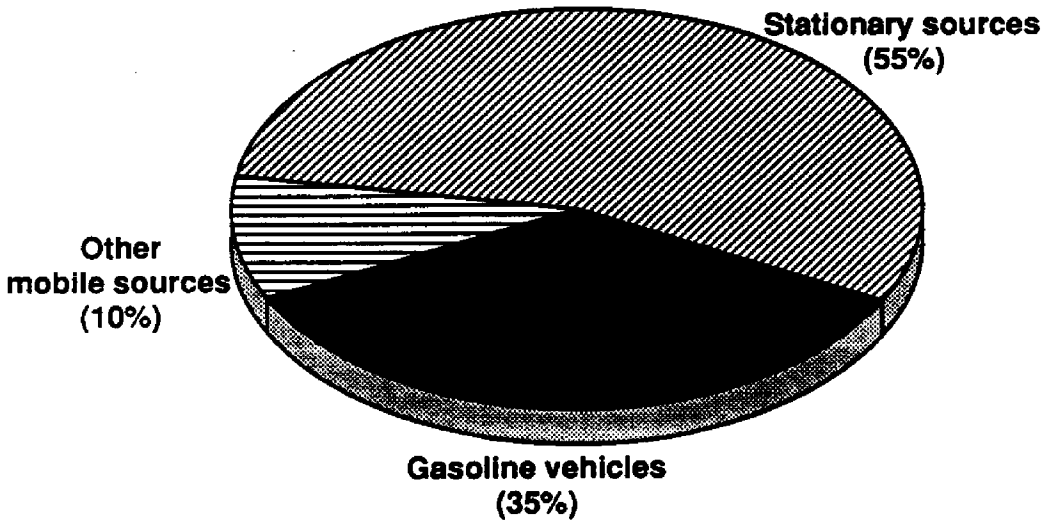
STATEWIDE CO EMISSIONS
1987 BASELINE INVENTORY



Total CO Emissions = 19,000 tons/day

Figure 3

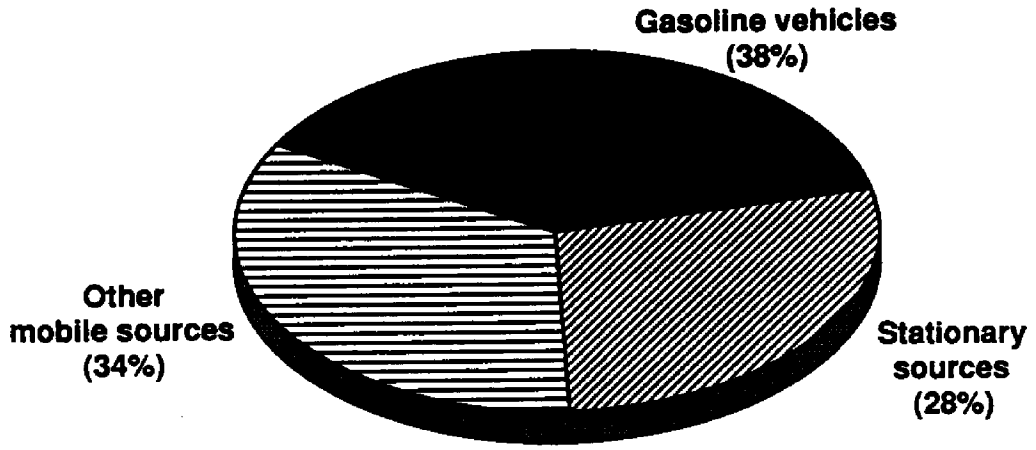
STATEWIDE VOC EMISSIONS
1987 BASELINE INVENTORY



Total VOC Emissions = 4,100 tons/day

Figure 4

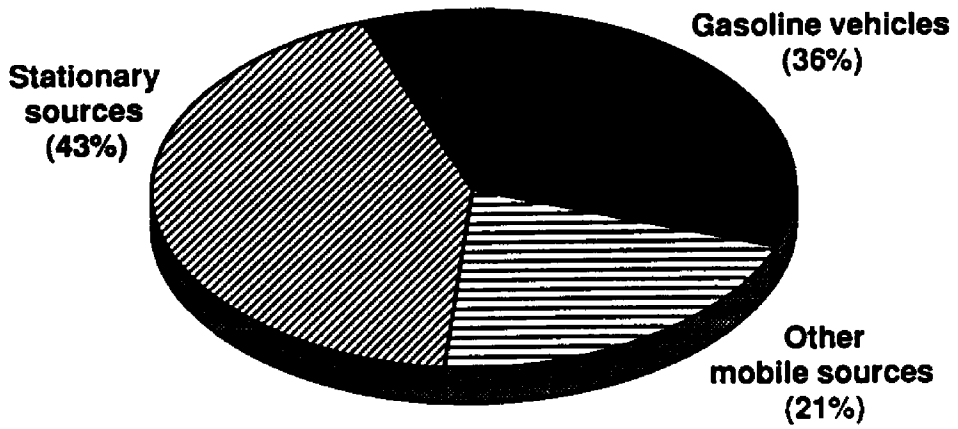
STATEWIDE NOx EMISSIONS



Total NOx Emissions = 3,400 tons/day

Figure 5

PM10 PRECURSORS



Total PM10 Precursor Emissions = 8,000 tons/day

1. Exceedance of the CO Standard

Typically, high concentrations of CO occur in localized areas where high traffic volumes exist (e.g., freeways and major surface streets). For the federal standard, there are eight areas that are designated as nonattainment (as shown in Figure 1, presented earlier). These areas include large metropolitan areas such as Los Angeles County and San Francisco County and smaller urban areas such as Fresno County.

There are 11 areas in California designated as nonattainment for the state standards for CO (as shown in Figure 1, presented earlier). These areas are located within 6 air basins. These air basins are the San Francisco Bay Area, South Coast, San Diego, Sacramento Valley, San Joaquin Valley, and Lake Tahoe. Exceedances of federal and state CO standards (both are 9.0 parts per million (ppm) for the eight hour average standard) are highest during the winter months which typically correspond to the months of October through February. There is, however, some deviation from this for some air basins. For example, in the South Coast Air Basin the CO standard exceedances occurred from September through March. Maximum concentrations of CO in nonattainment areas within the state ranged from 10.5 to 21.8 ppm during 1989.

2. Exceedance of the Ozone Standard

Exceedances of the state ozone standard (0.09 ppm for one hour average) are characterized by regional episodes with the highest levels normally occurring during the summer months, when the ozone forming potential from ozone precursors (VOC and NOx) is greatest. All air basins, except for the North Coast, Northeast Plateau, and Lake County, have exceedance periods for ozone. The ozone season varies among different air basins but most fall somewhere between February and November. However, some air basins experience year-round ozone exceedances, such as the South Coast Air Basin. Maximum exceedance concentrations within the state ranged from 0.13 to 0.34 ppm during 1989. For the periods between 1987, 1988, and 1989, the state standard for ozone was exceeded on the average of 178 days per year in Southern California and from 1 to 86 days per year in other areas of the state. The federal standard for ozone (0.12 ppm for one hour) is higher than the state standard. Therefore, there are fewer days per year during which the federal standard is violated in comparison to the state standard.

California's Reid vapor pressure (RVP) program is instituted during specified control periods for each air basin as part of control efforts to reduce motor vehicle evaporative VOC emissions and the contribution of these emissions to ozone formation. Presently, the RVP of gasoline is limited to 9 pounds per square inch (psi). In 1992, the RVP of gasoline will be limited to 7.8 psi during the control periods. Further reduction in RVP are recommended beginning in 1995 as part of federal and California reformulated gasoline program. The RVP control periods range from 4 to 7 months and generally correspond to each air basin's peak ozone season.

3. Other Criteria Pollutants

a. Exceedance of the NO_2 Standard

Only the South Coast and San Diego air basins have NO_2 exceedances of the state standard (0.25 ppm for one hour) for the three year period from 1987 through 1989. Maximum concentrations at exceeding monitoring stations in the South Coast Air Basin range from 0.26 to 0.34 ppm in 1989. The San Diego Air Basin did not exceed the state standard in 1989. Exceedances of the NO_2 ambient standard in the South Coast Air Basin occur from September to February. However, some past exceedances have occurred through May. Historically, the San Diego Air Basin has experienced NO_2 exceedances only in the month of January. Although only two air basins are in exceedance for the state NO_2 ambient air quality standard, the significance of NOx emissions are their contributions as precursors in the formation of ambient ozone and PM10.

b. Exceedance of the PM10 Standard

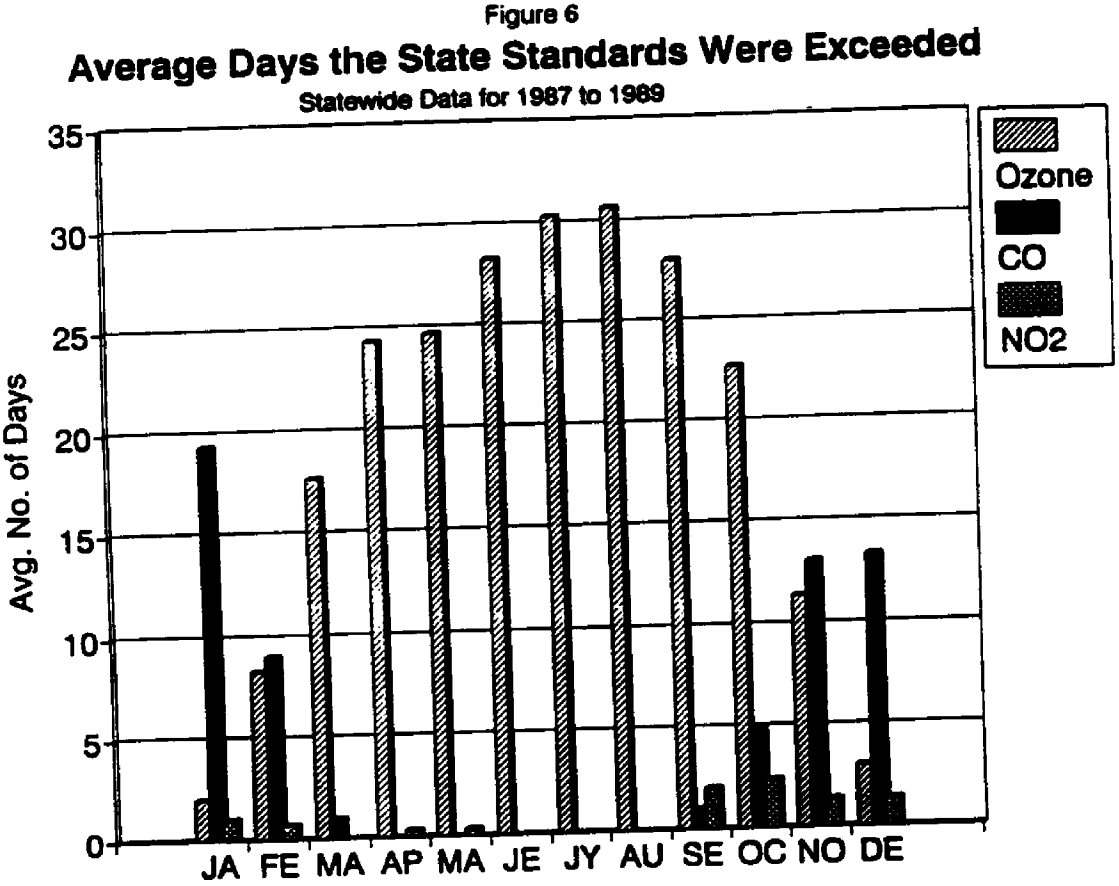
The state 24-hour PM10 standard is exceeded in 13 of the state's 14 air basins. An exceedance of the state standard is any value greater than 50 micrograms per cubic meter (μg/m3) over a 24 hour average. In many areas the standard is exceeded by wide margins with maximum concentrations ranging from 55 to 186 μg/m3. Air monitoring data collected by ARB shows that exceedances of the state PM10 standard occur every month of the year for all nonattainment air basins.

4. Overlapping Exceedance Periods

Overlapping exceedance periods are those months of the year when CO, ozone, and other ambient air quality standards are simultaneously violated. The occurrence of overlapping exceedance periods is important in assessing possible impacts that the proposed California wintertime oxygenated gasoline program can have on ambient air quality. Obviously, benefits of CO emission reductions will result from the proposed program. However, there are possible adverse effects such as increases in other pollutants which can have an overall adverse impact on air quality.

Figure 6 provides a statewide overview of the average number of days the state standards for CO, ozone, and NO_2 were exceeded and the frequency for each month for the years of 1987 through 1989. Figure 6 shows that overlapping exceedances occur from September through March. Figure 6 also shows that during September and October ozone violations are frequent, while CO violations are relatively few. Although, PM10 is not depicted in Figure 6, air monitoring data collected by ARB establishes that exceedances of PM10 occur year-round. Therefore, any adverse air quality impact associated with the proposed program could affect the exceedance periods of ozone, NOx, and PM10.

Figure 6


Average Days the State Standards Were Exceeded
Statewide Data for 1987 to 1989
Avg. No. of Days
35
30
25
20
15
10
5
0
JA
FE
MA
AP
MA
JE
JY
AU
SE
OC
NO
DE
Ozone
CO
NO2

Figures 7 and 8 compare the RVP control periods and peak CO seasons for the air basins that have overlapping periods. The RVP control periods are designed to reflect the peak ozone exceedance periods during which the volatility of gasoline is limited. For the South Coast Air Basin (Figure 7), the RVP control period extends from April through October while the peak CO season lasts from September through January. Therefore, the overlapping period for the South Coast Air Basin occurs for two months during September and October. For the rest of the air basins with overlapping periods (Figure 8), the RVP control period generally extends from May through October while the peak CO season lasts from October through January. The overlapping period for these air basins occurs for the month of October. Therefore, it is important to assure that the volatility of gasoline does not exceed the RVP volatility limits in the design of an oxygenate requirement for the overlapping CO and ozone exceedance periods. Also, since NOx is a precursor in the formation of ozone, it is important to assure that NOx emissions do not increase.

Figure 7

RVP CONTROL PERIOD AND PEAK CO SEASON MONTHS

SOUTH COAST AIR BASIN

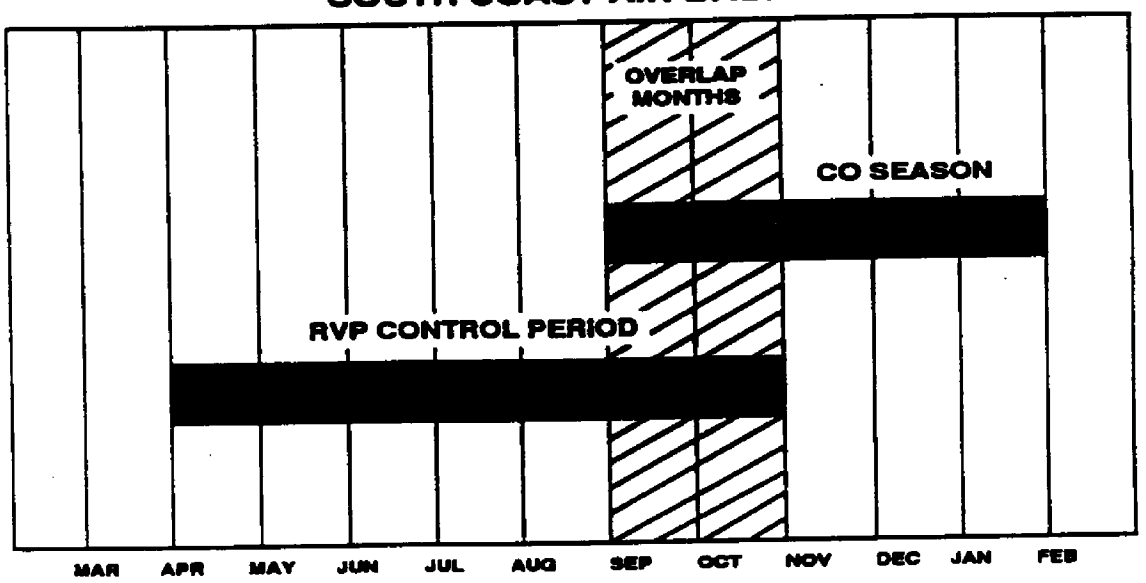
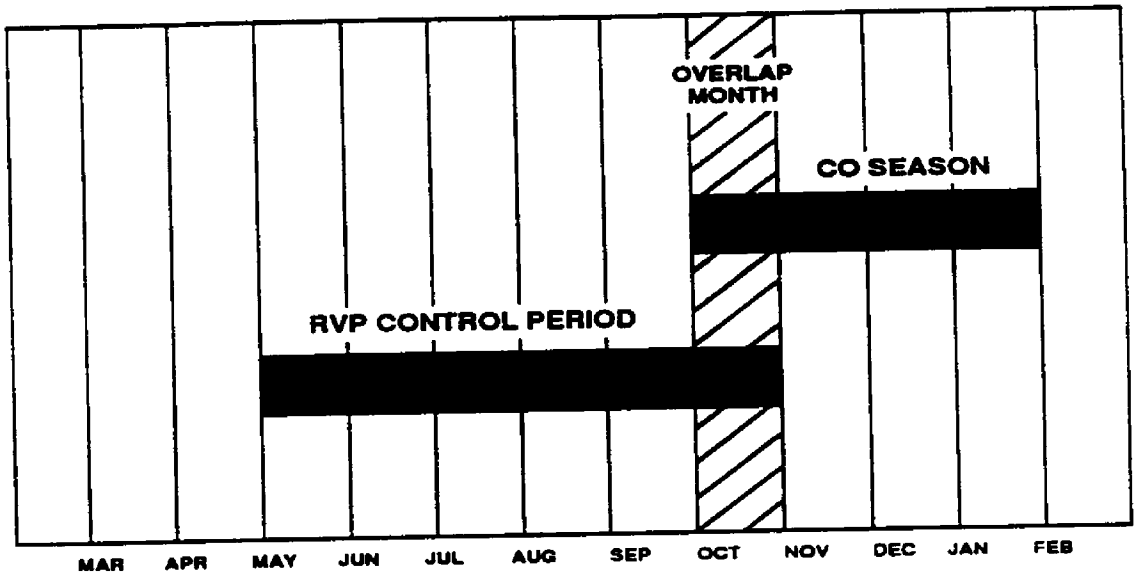


Figure 8

RVP CONTROL PERIOD AND PEAK CO SEASON MONTHS

AIR BASINS WITH OVERLAP*



* Sacramento Valley
San Joaquin Valley
Lake Tahoe
San Francisco
Mountain Counties
North Central Coast (June - October)

III.

EFFECTS OF OXYGENATES ON MOTOR VEHICLE EMISSIONS

The addition of oxygenates to a base stock gasoline affects the properties of gasoline in both performance and emission levels. Generally, the two classes of oxygenates being used in gasoline blends are alcohols and ethers. The most common oxygenates are ethanol and MTBE. Of the two classes, alcohols, due to their affinity for water, require that the gasoline they are blended into be free of water. Ethers, on the other hand, do not have this characteristic and, thus, are less troublesome as blending materials.

In designing the staff proposal for a California wintertime oxygenates gasoline program, staff reviewed available data on the effects of oxygenates on baseline motor vehicle emissions to determine the appropriate oxygenate levels that should not adversely impact motor vehicle emissions.

A. OVERVIEW OF TEST PROGRAMS

Various studies have been conducted to evaluate the effects of oxygenates on exhaust emissions. The studies reviewed to develop this report are listed below:

1. Studies for which data are available

- o EPA (Southwest Research Institute) ----------Ref. #5
- o American Petroleum Institute (API) ----------Ref. #1
- o Auto/Oil Air Quality Research Program ----------Ref. #7
- o Radian Corporation ----------Ref. #3

Most of the studies have been conducted on MTBE blends at 2.7 percent oxygen by weight and ethanol blends at 3.5 percent oxygen by weight. Generally, the data from these studies show that for ethanol at 3.5 percent oxygen, there is a significant increase in NOx emissions. For MTBE blends at 2.7 percent oxygen by weight, some data show an increase in NOx emissions, while other data show decreases or no significant change. Some data also support the contention that the NOx effect may be dependent not only on the oxygen added to gasoline, but on the properties of the compound supplying the oxygen.

2. Ongoing Test Progra

a. Automotive Testing Laboratory, Inc. (ATL/EPA) Study

EPA is sponsoring a test program at Automotive Testing Laboratory (ATL) to investigate the effect of oxygenated fuels on motor vehicle emissions. The study is currently under way. Data is being generated on vehicles tested on a base fuel and fuels with MTBE added to give an oxygen content of 2.0 percent by weight and fuels with ethanol added to give an oxygen content of 3.5 percent. The fuels were also adjusted to determine if lowering the aromatic hydrocarbon content changes the effect of oxygenates on emissions. Data is now available for 14 vehicles and the program is expected to be completed by mid-October. EPA is sponsoring this program in an attempt to better establish the response of motor vehicle emissions at low oxygen levels, particularly for NOx emissions. Generally, the available data show that both MTBE and ethanol added to gasoline result in reductions in CO emissions. MTBE added to give a 2.0 percent oxygen content results in no significant increase in NOx emissions. Ethanol added to give a 3.5 percent oxygen content results in increases in NOx emissions on the order of about 12 percent.

b. ATL/ARB Study

ATL under contract with ARB is conducting tests to determine the effect of low-oxygenate gasoline blends on emissions from California vehicles. ATL is testing four sets of motor vehicle types; noncatalyst, oxidation catalyst, three way catalyst (closed-loop), and three way catalyst (advanced technology systems).

The fuel matrix consists of oxygenated gasoline blends at 2.0 percent and 2.7 percent oxygen content by weight using three oxygenates; ethanol, MTBE, and ethyl t-butyl ether (ETBE). Early results from this study indicate general agreement with previously reported data. Staff will continue to evaluate the data as it becomes available. Complete data from this program are expected to be available in the near future.

B. EFFECTS OF OXYGENATES ON MOTOR VEHICLE EMISSIONS

1. Effects on Carbon Monoxide

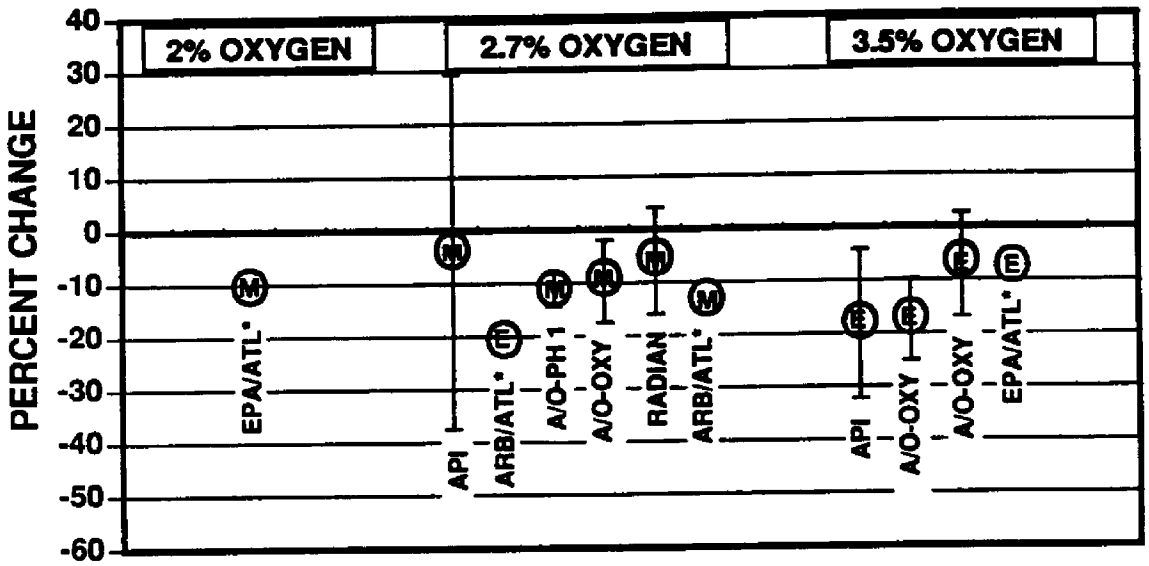
The addition of oxygenates to gasoline has the effect of leaning the combustion mixture due to the increase in oxygen content supplied in the gasoline. This results in improved combustion and significant reductions in carbon monoxide. Based on the studies reviewed, CO emissions are plotted as a function of oxygen content in Figure 9. This figure shows that generally CO is reduced by about 3 to 20 percent. All of the studies agree that the use of oxygenates in gasoline results in significant reductions in CO emissions.

2. Effects on Oxides of Nitrogen (NOx)

The data on oxygenated gasoline blends at low levels of oxygen content are limited. Most of the testing has been done at 2.7 percent oxygen by weight for the MTBE blends and at 3.5 percent oxygen by weight for the ethanol blends.

Figure 9

CO EMISSIONS RESPONSE



M=MTBE
E=ETHANOL
* Preliminary data

In recognition of the uncertainty of the effects low oxygenate levels in gasoline have on motor vehicle NOx emissions, EPA and ARB have recently contracted with ATL to conduct definitive test programs to evaluate the effects on NOx emissions. As discussed previously in the ATL/EPA study, early results show that MTBE added to gasoline to result in a 2.0 percent oxygen content by weight have no significant increase in NOx emissions. Also, early results from this study and the ARB/ATL study indicate that ethanol added to gasoline at a 3.5 percent oxygen content by weight can significantly increase NOx emissions which confirms previous studies. The regression equation developed for the effect of MTBE on NOx emissions for the first phase of the Auto/Oil study also predicts a no NOx increase for 2.0 percent MTBE. Shown in Figure 10 is the relationship of oxygen levels on the effects of MTBE and ethanol on NOx emissions. This figure appears to support the supposition that the NOx increase is related to the oxygen content of gasoline; thus, ethanol and MTBE would tend to have similar effects on increasing NOx emissions.

In consideration of this data, staff has recommended in the proposed program that the oxygen level be limited to an average 2.0 percent by weight, to prevent significant increases in NOx emissions from the use of oxygenates. Staff are still evaluating data and expect to have the results of additional vehicle tests in the near future. If further evaluation indicates that adjustments to the proposed program are needed to avoid adverse impacts, staff will make such recommendations at the Board hearing.

3. Effects on Volatile Organic Compounds

Emissions of exhaust VOCs are reduced by using oxygenated gasoline; however, this reduction is less than for CO. The response to oxygenated gasoline varies with vehicle class. The results for the current vehicle fleet range from an increase of about 10 percent to a decrease of about 20 percent. Generally, the average reduction of exhaust hydrocarbons is about 5 to 10 percent for oxygenated fuels.

Oxygenates can affect the volatility of gasoline depending on the type and quantity of the oxygenate being used and the properties of the base gasoline blend. Generally, alcohols increase the RVP of gasoline significantly more than ethers. Of the two main oxygenates currently being used, adding ethanol to gasoline tends to increase the RVP of the blend by about 1 psi, while the addition of MTBE results in no significant increase. Figure 11 shows the effects of oxygenates on the RVP of gasoline for ethanol and MTBE at different percentages of oxygen in gasoline.

Figure 10

NOx EMISSIONS RESPONSE

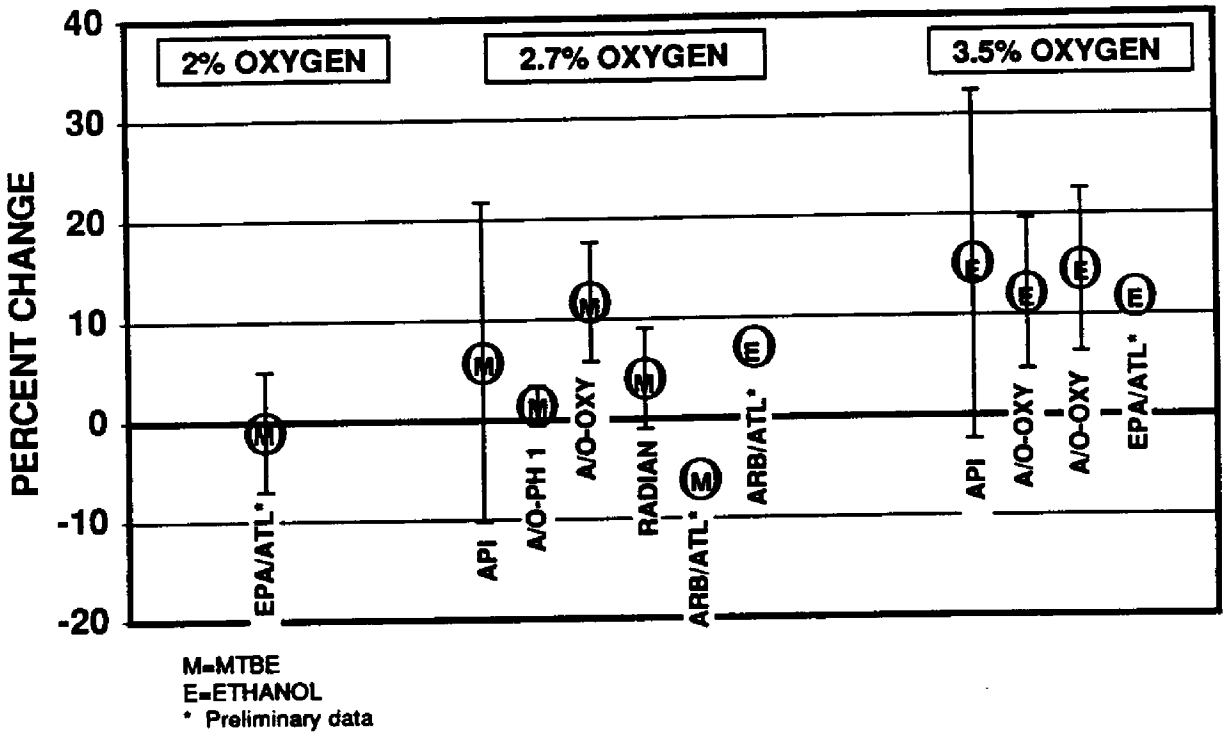
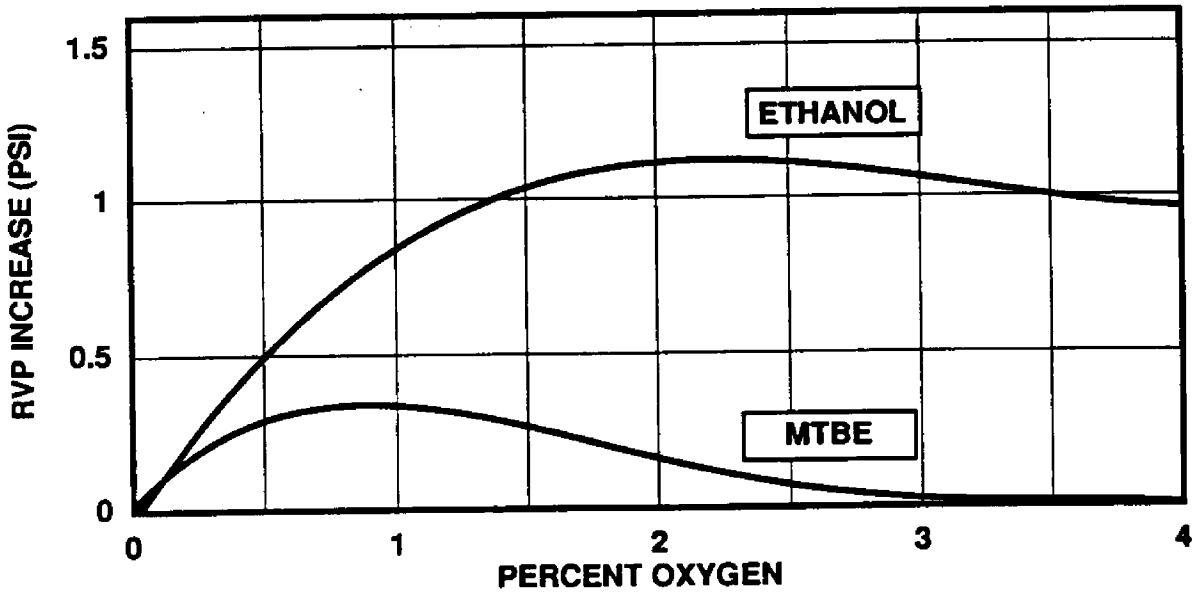


Figure 11

REID VAPOR PRESSURE RESPONSE



IV.

DISCUSSION OF PROPOSED CALIFORNIA WINTERTIME OXYGENATES GASOLINE PROGRAM

The proposed California wintertime oxygenates gasoline program is designed to meet the requirements in the CAA and to address the specific air quality needs of California. To accomplish this, staff have proposed minimum and maximum oxygenate levels that are lower than the level specified in the CAA. As previously discussed, the deviation from the federal requirement is recommended to ensure that efforts to attain the federal and state ambient air quality standards for ozone, NO_2, and PM10 would not be hampered while implementing the most effective wintertime oxygenates gasoline program possible in California. Staff believe that the proposed program will meet the intent of the CAA requirements for CO nonattainment areas by achieving the maximum CO reduction possible, while not adversely impacting attainment of the federal and state ambient air quality standards for other criteria pollutants. Because we are proposing to deviate from the CAA requirements, a waiver request to EPA will be required.

1. Proposed Oxygenate Levels

The proposed program specifies oxygen content levels that all gasoline sold in California must meet during specified periods of the year. The proposed regulation would set a minimum oxygen content of 1.8 percent by weight and a maximum oxygen content of 2.2 percent by weight. Also, no minimum oxygenate content is proposed during the months when the RVP regulatory control periods overlap into the CO regulatory control periods. However, the maximum oxygen content of 2.2 percent by weight would still apply during overlap months.

The existence of periods during the year when ambient levels of CO, ozone, NO_2, and PM10 can be simultaneously violated creates concerns in selecting the appropriate approach for controlling motor vehicle CO emissions through the use of oxygenates in gasoline. The minimum and the maximum oxygen levels are to ensure that the program achieves maximum CO emission reductions while not adversely impacting air quality. As previously discussed, increasing the oxygen content of gasoline reduces exhaust CO emissions. However, NOx emissions can increase at higher levels of oxygenate usage. As discussed in Chapter III, studies indicate that ethanol added significantly in excess of 2.0 percent by weight oxygen content in gasoline can result in NOx increases. The specified average oxygen content of 2.7 percent by weight contained in the federal CAA would result in increases of NOx and evaporative emissions, if ethanol is used as the oxygenate.

The exemption for no oxygenate blending during periods of overlap between the RVP and CO control periods addresses California's gasoline RVP program that limits the volatility of gasoline sold during the peak ozone season (summer months). Generally, the RVP control periods run from April to October adjusted to coincide with the peak ozone seasons within each air basin. Since the CO season of several air basins overlap into their respective RVP control periods, a possible problem exists if an increase in gasoline RVP occurs when ethanol is used as the oxygenate. Although MTBE does not have this problem, the limited supply of MTBE could result in shortages. To avoid this problem, staff recommends not requiring the use of oxygenates during the overlap months in each air basin. This allows gasoline producers not to blend oxygenates if suitable oxygenates (e.g., MTBE) are not available during this period. Staff also recommends that the maximum oxygen content of 2.2 percent by weight still apply during the overlap months to ensure that the potential use of oxygenates does not adversely affect air quality during this period through increases in NOx emissions.

As mentioned previously in Chapter I, the proposed regulation for Phase 2 gasoline specifications become effective on January 1, 1996, which supercedes the wintertime oxygenates program. However, the proposed Phase 2 specifications incorporate the wintertime minimum and maximum oxygen content requirements but will be implemented year-round. The effective date of January 1, 1996, allows adequate lead time for producers to make available suitable oxygenates for the year-round program.

2. Applicability

The proposed program applies statewide and to all California gasoline. No person will be allowed to sell, offer for sale, dispense, supply, or offer to supply, or transport gasoline that does not meet the specified oxygen content. The regulation applies during the regulatory control periods which range from 4 months to 6 months. The CAA specifies 4 months as the minimum period. The EPA administratively establishes these periods and may establish periods beyond 4 months. The regulatory control periods proposed by EPA for the program have been expanded by staff to apply statewide. The proposed control periods are specific to each nonattainment air basin and are as follows:

o South Coast Air Basin	(September 1 through February 29)
o Sacramento Valley Air Basin	(October 1 through January 31)
o San Joaquin Valley Air Basin	(October 1 through January 31)
o San Francisco Bay Area Basin	(October 1 through January 31)
o Lake Tahoe Air Basin	(October 1 through January 31)
o Great Basin Valley Air Basin	(October 1 through January 31)
o Mountain Counties Air Basin	(October 1 through January 31)
o North Coast Air Basin	(October 1 through January 31)
o Lake County Air Basin	(October 1 through January 31)
o Northeast Plateau Air Basin	(October 1 through January 31)
o North Central Coast Air Basin	(October 1 through January 31)

- o San Diego Air Basin (November 1 through February 29)
- o South Central Coast Air Basin (November 1 through February 29)
- o Southeast Desert Air Basin (November 1 through February 29)

3. Regulated Activities

The oxygen content standards would apply to gasoline sold or supplied throughout the distribution system, as is the case with most of the ARB's other fuels regulations. This enhances the potential enforceability of the regulation and encourages entities involved in fuel distribution to help assure compliance. However, when ethanol is used as an oxygenate, it typically is not added to gasoline before the gasoline reaches the terminal. Therefore, the proposed regulation provides that prohibitions on selling gasoline not complying with the minimum oxygen content standards do not apply to transactions occurring before the gasoline is supplied from the final distribution facility, if the person selling or supplying the gasoline demonstrates that he or she has taken specified precautions to assure it will be brought into compliance before it is supplied from the final distribution facility. Since there is less control where the gasoline is being oxygenated by a different party, in that case the person selling or supplying the gasoline must obtain a written statement from the recipient stating that the gasoline will be brought into compliance with the minimum oxygen content requirement. This approach is patterned after similar provisions in the ARB's regulation on gasoline deposit control additives.

As in the Phase 1 RVP regulation, the proposed oxygenate regulation includes provisions intended to clarify the applicability of the standards when gasoline is sold upstream in one control area or time period and dispensed into vehicles in a different area or time period. There will be no liability for otherwise covered upstream transactions if the seller demonstrates that reasonably prudent precautions have been taken to assure that the gasoline will only be delivered to a retail outlet when it is not subject to oxygenate requirements.

Also like the Phase 1 RVP regulation, the proposed oxygenate regulation provides that the oxygen content limits do not apply to sales to motor vehicles during the control period where the last delivery to the storage tank from which the fuel was dispensed occurred more than 14 days before the start of the control period. This protects operators of stations whose very low throughput and infrequent deliveries prevent the timely replacement of nonoxygenated gasoline with oxygenated gasoline.

The regulation would provide that each retail sale of gasoline for use in a motor vehicle, and each dispensing of gasoline into a motor vehicle fuel tank, is also deemed a sale by any person who previously sold the fuel in violation of the substantive standards. This provision would help assure that Health and Safety Code Section 43016 "per vehicle" penalties will apply to persons who sell noncomplying gasoline to distributors, service stations or bulk purchaser-consumers. It is based on essentially identical language in several other ARB fuels regulations.

4. Sampling and Test Procedures

Sampling and testing of gasoline to determine compliance with the requirements of the proposed program will be done using the American Society of Testing Materials Method D 4815-88. The minimum and maximum range of 1.8 percent oxygen content by weight and 2.2 percent oxygen by weight is intended to address the tolerance of the specified test method and the ability to blend gasoline to meet a specification. Staff believes that producers and blenders will target a 2.0 percent oxygen by weight to stay within the required oxygen levels.

5. Variance Provisions

The proposed program contains provisions under which a person unable to comply with the specified oxygen levels in gasoline which is beyond the person's reasonable control may apply to the Executive Officer for a variance. The applicant must provide specific information to support the request for variance and specify the earliest possible date for compliance. The provision for granting a waiver specifies that the Executive Officer must find that:

- for reasons beyond the applicant's control, requiring compliance would result in an extraordinary economic hardship; and
- public interest in granting a variance outweighs the public interest in avoiding increased emissions of air contaminants that would result from issuing a variance; and
- the compliance plan proposed by the applicant can be reasonably implemented and will achieve compliance as expeditiously as possible.

V.

IMPACTS OF PROPOSED PROGRAM

A. AIR QUALITY AND EMISSION REDUCTIONS

Implementation of the proposed California wintertime oxygenates gasoline program will reduce emissions of CO and VOCs from gasoline fueled vehicles during the winter. During the winters of 1992/93, CO emission reductions are estimated to be about 1200 tons per day and VOC emission reductions are estimated at 20 tons per day. The corresponding percent reductions are 10 percent for CO and 3 percent for VOC. The emission reduction estimates are based on using the regression equation from the Auto/Oil program and the ARB wintertime CO emission inventory.

B. ECONOMIC IMPACTS

1. Demand

In estimating the projected demand for oxygenates to meet the proposed program, a number of factors were considered which included the CO regulatory control periods, the projected total gasoline consumption during the CO control periods, oxygenate requirements, spillover (e.g., use of oxygenates outside of the control periods), current oxygenate demands, and the potential for EPA waivers. Based on a projected gasoline use of about 4.3 billion gallons for the winters of 1992/93 and the usage ratio of MTBE and ethanol of 75/25, the expected demand for MTBE and ethanol is about 350 million gallons and 60 million gallons, respectively.

2. Supply

The increase in demand for oxygenates must be assessed to determine that an adequate supply of oxygenates are available to satisfy the requirements of the proposed program. Staff, in their evaluation of the supply of oxygenates, considered California's current production capacity, expansion capacity, nameplate capacity, and storage capacity.

California is not a large producer of either MTBE or ethanol. Current production of MTBE in California is about 190,000 gallons/day from two plants and production of ethanol is estimated to be about 19,000 gallons/day from three facilities. Based on staff's estimated oxygenate demand during the CO control periods and that MTBE will be used to satisfy 75 percent of the demand, California will need to import about 270 million gallons of MTBE for the 1992/93 CO season. About 60 million gallons of ethanol for the 1992/93 CO season will need to be imported, assuming that ethanol will be

used to meet about 25 percent of the oxygen requirements. We expect that MTBE would be imported principally from the Gulf Coast states while ethanol would be imported almost exclusively from the Midwest.

The EPA conducted a study to evaluate the impacts of its proposed oxygenate requirements on the nation's supply and demand of MTBE and ethanol. The EPA's average required oxygen content of gasoline is set at 2.7 percent by weight. This study assessed the amount of oxygenates (MTBE and ethanol) needed to meet the requirement for the over 40 nonattainment cities nationwide. Domestic production of MTBE and ethanol was estimated by EPA using a range from low to high capacity estimates. Six scenarios were evaluated and EPA concluded that in 4 of the scenarios there would be an oxygenate surplus. Based on EPA's study and discussions with others, staff expects sufficient oxygenates will be available to meet the California demand.

3. Cost

Staff has estimated the cost of complying with the proposed oxygenate program, assuming that MTBE will be used to meet 75 percent of the oxygen requirement and ethanol the remaining 25 percent. Total cost for supplying oxygenates to California, including transportation, is estimated to be about $1.17/gallon for MTBE and $1.32/gallon for ethanol. Thus, the cost to obtain sufficient amounts of MTBE and ethanol to meet the requirements of the proposed program is estimated to be approximately $130 million, including the costs due to the loss in revenue from the federal motor vehicle fuel tax exemption. The total cost per gallon of gasoline for the 1992/93 CO season due to the oxygenate requirement is estimated to be about 3 cents per gallon of gasoline. This translates into a cost of 50 cents per pound of CO controlled.

4. Small Business Impacts

Small businesses are defined by Government Code Section 11342 et seq. The Code requires the ARB to discuss possible adverse impacts that the proposed program could have on small business. Staff expects that any small business affected by the proposed program will be able to pass any compliance expenses through to the consumers in the form of higher product costs. In view of this, staff believe that the adoption of the proposed program will not result in any significant adverse impact on small businesses.

C. POTENTIAL ENVIRONMENTAL IMPACTS

Staff believe that implementation of the proposed program will result in a net air quality benefit from significant reductions of wintertime CO emissions. Staff has not identified any adverse environmental or safety impacts due to the use of oxygenated gasoline that do not already exist with conventional gasoline. Staff believe that the potential safety hazards and environmental impacts associated with oxygenated gasoline are no greater than the potential impacts associated with conventional gasoline that would otherwise be used. The production and use of oxygenated gasoline are not expected to increase emissions of greenhouse gases that contribute to global warming or pollutants that may contribute to stratospheric ozone depletion.

REFERENCES

1. American Petroleum Institute, Health and Environmental Sciences, Effects of Fuel RVP and Fuel Blends on Emissions at Non-FTP Temperatures, Volume I: Interim Summary Report, July 1991.

2. Auto/Oil Air Quality Improvement Research Program, Technical Bulletin No. 4, Mass Exhaust Emissions Results from Reformulated Gasolines in Older Vehicles, May 1991.

3. Radian Corporation, Prepared for the Western States Petroleum Association, The Exhaust Emissions Effects of Ethanol and Methyl-t-Butyl Ether in Gasoline Fuel Blends, Final Report, May 1991.

4. State of California Air Resources Board, Technical Support Division, Report to the California State Legislature. Prospects for Attaining the Ambient Air Quality Standards for Suspended Particulate Matter (PM10), Visibility Reducing Particles, Sulfates, Lead, and Hydrogen Sulfide, April 1991.

5. Southwest Research Institute, Prepared for the Environmental Protection Agency, Assessment of Unregulated Emissions from Gasoline Oxygenated Blends, July 1990.

6. State of California Air Resources Board, Technical Support Division, Emissions Inventory 1987, March 1990.

7. Auto/Oil Air Quality Improvement Research Program, Technical Bulletin No. 1, Initial Mass Exhaust Emissions Results from Reformulated Gasolines, December 1990.

8. State of California, Air Resources Board, Reformulated Gasoline: Proposed Phase I Specifications, Staff Report and Technical Support Document, August 13, 1990.

9. Piel, William J., ARCO Chemical Company, The Role of MTBE in Future Gasoline Production, Paper No. 47d. Presented at the 1988 Spring National Meeting of American Institute of Chemical Engineers, March 6-10, 1988, New Orleans, LA.

10. Sugimoto, Roy, (DeWitt & Company Incorporated), World Wide MTBE Capacities, July 10, 1991.

11. Personal communication with Dr. Roy Sugimoto on September 12, 1991.

12. DeWitt & Company Incorporated, MTBE/Oxygenates/New Fuels, No. 288, August 22, 1991.

13. New Fuels Report, Vol. 12 No. 29, July 22, 1991.

14. U.S. Environmental Protection Agency, "Analysis of Oxygenate Supply and Demand, 1992 Carbon Monoxide Oxygenate Program", no date.

15. Piel, William J., "The Role of Ethers in Low-Emission Gasoline", National Conference on Motor Fuels and Air Quality, Washington, D.C., October 3-5, 1989.

16. ARCO Chemical Company, "Assessment of Oxygenate Supply/Demand Balances for Proposed Clean Air Bills", September 11, 1990.

17. U.S. Environmental Protection Agency, Draft Regulatory Impact Analysis - Reformulated Gasoline and Anti-Dumping Regulations, July 1991.

18. State of California Air Resources Board, Proposed Regulation for Low-Emission Vehicles and Clean Fuels, August 13, 1990.

19. State of California Air Resources Board, Technical Support Division, Annual Summary of Air Quality Data, Gaseous and Particulate Pollutants, Volumes XIX, XX, XXI.

20. Owen, Keith and Trevor Coley, Automotive Fuels Handbook, Society of Automotive Engineers, Inc., 1990.