Cost of Reducing Aromatics and Sulfur Levels in Motor Vehicle Fuels

Volume I — Executive Summary

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EXECUTIVE SUMMARY

I.   INTRODUCTION

A.   OVERVIEW

The California Air Resources Board (ARB)[1] retained Arthur D. Little, Inc., to conduct a study that was allied with its program to reduce emissions from vehicular sources. ARB is developing the following three component approach to reducing emissions:

o   Promulgating increasingly stringent regulations for new vehicles;

o   Including diesel-powered vehicles in its smog-check program; and

o   Improving the quality of motor fuel.

Arthur D. Little, Inc., was retained to analyze the third approach, i.e., reducing emissions from vehicular sources by improving the quality of motor fuel. In undertaking the study effort, we adopted an approach using a series of refinery models to estimate the cost of improving the quality of motor fuel (1) by reducing aromatics levels in gasoline and diesel fuel, and (2) by reducing the content of sulfur in diesel fuel. Such reductions will improve the quality of the air in California through:

o   The reduction of the aromatics contained in evaporative emissions; and

o   The reduction of aromatics, polycyclic aromatic hydrocarbons (PAH), nitrated polycyclic aromatics (NPAH), sulfur oxides (SO_x), nitrogen oxides (NO_x), and particulates in automotive emissions.

B.   INDUSTRY BACKGROUND

Automotive gasoline and diesel fuel contain high levels of aromatics. Aromatics are a high-octane gasoline component which can range from 18% to 45% of gasoline with the average in California about 33%. Although some of these aromatics, such as benzene, have been identified as carcinogenic, gasoline aromatics levels have been rising with increased octane requirements, because of the phaseout of tetra-ethyl lead (TEL). Such processes as catalytic reforming have been designed to increase rather than decrease aromatics levels to improve gasoline octane. Further, there has been little incentive to install processes that will extract light aromatics (benzene, toluene and xylenes) on the West Coast, since petrochemical processing is concentrated on the Gulf Coast. Unless controls are introduced, gasoline aromatics levels are expected to increase because of the

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[1]   A list of acronyms is included at the end of this Executive Summary.

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elimination of lead from gasoline and the increased demand for high-octane, unleaded premium gasoline.

Diesel fuel aromatics levels can range from 17% to 43% with the average in California at about 31%. Diesel aromatics levels have been gradually rising, because of the increased conversion of heavy oils to light products through catalytic cracking. Unless controls are introduced, diesel aromatics levels are expected to continue to increase because of increased levels of conversion processing. However, in the case of diesel fuel, aromatics are not desirable. In fact, increased aromatics levels have lowered diesel cetane numbers (a measure of diesel automotive performance). Although many cracked diesel components are hydrotreated to reduce sulfur levels, generally the severity of hydrotreating is not sufficient to significantly reduce aromatics content by saturation.

Diesel sulfur contents can range from 0.05 to 0.98 wt% (exceeding ASTM specification of 0.5 wt%); they average about 0.3 wt% in California. Increased crude oil sulfur levels, declining conversion feed quality and increased conversion levels, have been partially offset by increased diesel hydrotreating to remove sulfur. Thus diesel sulfur content will likely remain near current levels without some form of regulation. Diesel sulfur levels are currently limited to 0.05 wt% in the Los Angeles Basin. Diesel sulfur levels can be reduced (at some cost to refiners) through additions to hydroprocessing capacity.

C.   PROJECT OBJECTIVES

The objectives of our research project efforts were to:

o   Develop linear programming (LP) models of California refineries;

o   Use these models to estimate the cost of reducing various types of aromatics levels in automotive gasoline and diesel fuel, and sulfur levels in diesel fuel;

o   Provide the ARB with cost equations that will enable the Board to update or extend the results of this analysis;

o   Scale up the individual refinery costs to obtain the overall cost impact to California; and

o   Determine the impact of improving automotive fuel quality on refinery emissions, automotive emissions, and automotive performance.

D.   SUMMARY OF RESULTS

1.   Costs of Reducing Diesel Sulfur and Aromatics

It is technically feasible to reduce diesel sulfur to 0.05 wt% using currently available commercial processes at an average cost in

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California of 6 ¢/gallon. Diesel aromatics level can be reduced to 10% using a combination of currently available commercial processes and developing process technology at an average cost of 28 ¢/gallon.

Major refinery changes will be required for new processing capacity, and all components of refinery costs will increase.

Cost impact in individual refinery groups will vary significantly because of the differences in size, existing process configuration, and current diesel quality as shown in Figure 1. Costs for sulfur reduction to 0.05 wt% will vary from 2 to 35 ¢/gallon and costs to reduce aromatics to 10% will vary from 11 to 126 ¢/gallon as shown in Figure 2.

Both sulfur and aromatics reduction costs will increase if new hydrogen plant capacity is required to support all new hydrogen processing investment.

Diesel sulfur and aromatics reduction costs are sensitive to initial sulfur and aromatics level, refinery configuration, and refinery size. Costs for reduction of aromatics levels to 10% are sensitive to methanol price. Availability of low-sulfur/low-aromatics diesel blendstocks would dramatically reduce costs, but it is uncertain that these blendstocks will be available. Costs will likely increase in the future because of increased refinery utilization, diesel demand, and energy price.

Diesel cetane index will be improved as a result of reductions of diesel sulfur and aromatics level.

2. Costs of Reducing Gasoline Aromatics

Gasoline aromatics content can be reduced in 1991 by an average of 18% of base levels while maintaining base octane with process investment at an average cost of 7 ¢/gallon.

Aromatics reduction will vary from 5% to 21% by refinery type and costs will vary from 6 to 16 ¢/gallon. Major refinery changes will be required for new processing capacity and all components of refinery cost will increase.

Refiners will not be able to make gasoline demand grade split and octane without substantial investment in 1995. As a result of increased octane requirements in 1995, gasoline aromatics content can only be reduced by an average of 15% with new process investment and average costs increase to 9 ¢/gallon.

Gasoline aromatics reduction costs are sensitive primarily to refinery octane constraints which are a function of gasoline octane requirements and refinery configuration. Gasoline aromatics content can be reduced by 50% in 1995 at an average cost of 17 ¢/gallon with unlimited purchase of high octane, low aromatics blendstocks, but it

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is uncertain if these blendstocks will be available. Costs for gasoline aromatics reduction will likely increase in the future because of increased octane requirements and energy price.

Gasoline benzene content will be reduced along with total aromatics content but at a somewhat different rate depending upon refinery configuration.

E.   BASIS OF ANALYSIS

In this study, we focussed on the refining cost of reducing diesel and gasoline contaminant levels in California. We developed these costs using an LP modelling technique to measure the difference in refining costs relative to producing current quality diesel and gasoline. While the absolute levels of cost for each case are of interest, the increase in costs to reduce diesel and aromatics levels are of critical importance.

We selected the November 1987 California Energy Commission "Fuels Report" as the basis for this study since it was a published survey that had been reviewed by the industry and contained complete and consistent energy and price forecasts. Other published energy forecasts did not give the required regional product demand necessary for our analysis. While we fully recognize the uncertainty in future energy and demand forecasts, it is not necessary to directly analyze a wide range of scenarios in order to obtain a reasonable estimate of the increase in refining costs to reduce diesel and gasoline contaminant levels, since the unit cost to reduce contaminant levels is mainly a function of initial and final product quality rather than the absolute level of demand.

The major impact of the price forecast on the overall cost of reducing diesel and gasoline contaminant levels is on refinery feedstock costs which can be directly related to marginal energy cost. We have provided feedstock cost equations in this study to adjust our results for differences in marginal energy cost.

We selected Alaskan North Slope (ANS) crude as the marginal crude for this analysis. Although not all refineries in California process ANS crude, ANS is clearly the marginal, price-setting crude on the U.S. West Coast. There is a surplus of ANS crude on the West Coast and it makes up any swing in overall California oil demand, with the surplus moving to the U.S. Gulf Coast.

We maintained all primary product demands at base levels in this analysis such that loss in volume caused by aromatics removal, sulfur removal, changes in process severity, etc., would have to be replaced either through increased crude oil processed or purchase of outside feedstocks. Allowing other prime product volumes to vary would allow refiners to dispose of unwanted sulfur and aromatics in alternate products such as military diesel and No. 2 fuel, that have limited demand in California.

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The results presented in this executive summary are based on the total cost of contaminant reduction to each level. The marginal costs to reduce contaminants at each level are discussed in the main body of the report.

F.   STUDY QUALIFICATIONS AND LIMITATIONS

1.   Qualifications

The technique used for this study, linear programming analysis, is one that is widely used by the petroleum industry to optimize refinery operations and to assist in capital investment decisions. When used to represent, in a single model, a number of different refineries, some over-optimization of capacity utilization and blending inevitably occurs. LP modelling of individual refineries is not a feasible approach for studies of this type because of the enormous work effort involved and the inavailability of the detailed data required on each refinery. By concentrating its analysis on small groups of refineries with similar characteristics, ADL believes that a reasonable assessment of the likely costs of reducing sulfur and aromatics contents has been made. However, these results must be interpreted as providing an indication of the broad level of costs, rather than as giving an exact prediction of the costs that will actually be incurred.

2.   Limitations

In our analysis we did not include other product quality restrictions under consideration by the U.S. EPA and the ARB, such as:

o   Reduction of summer gasoline volatility by up to 2.5 RVP; and

o   Reduction of the gasoline olefins content.

In addition, we did not consider the effects of seasonality on automotive fuel demand, gasoline vapor pressure, and refinery butane balance.

Although we analyzed the impact of three levels of diesel segregation, incremental refinery storage or product supply costs associated with different segregation levels were not considered.

While we analyzed the impact on refinery emissions from improving automotive fuel quality, we did not examine the cost or availability of environmental permits or emission offsets required for refinery modifications.

Offsite requirements, including environmental facilities, were based on standard factors and did not reflect on a refinery-specific analysis.

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We did not consider the impact of decreasing the specific gravity of diesel and gasoline fuels on automotive fuel consumption, nor demand on refineries. Nor did we consider the impact on demand of increases in diesel and gasoline price caused by quality regulation.

Rather than develop an independent forecast, we used the latest CEC forecast, published in the November 1987 "Fuels Report", as the supply/demand and price basis for our analysis. We were not required to evaluate a range of supply/demand scenarios in this analysis.

Finally, the level of accuracy of costs for this study is limited by the level of accuracy of process investment costs which are estimated at $\pm$25-30% for commercial process technology and $\pm$40-50% for developing process technology.

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II. FINDINGS AND CONCLUSIONS

The major findings and conclusions of our study are summarized below:

A. DIESEL AND GASOLINE QUALITY WITHOUT ADDITIONAL REGULATIONS

o   Current diesel content is about 0.3% sulfur and 31% aromatics, and there will be little change in quality through 1995.

o   Current gasoline content is about 33% aromatics and 1.85% benzene.

o   Gasoline aromatics levels are expected to remain about constant to 1991, but benzene levels are expected to increase to about 2.0%.

o   By 1995 because of isomerization, MTBE, and etherol process additions to meet higher octane requirements, gasoline aromatics levels are expected to decline to about 32% and benzene levels to 1.9%.

B. OPTIONS FOR REDUCING DIESEL SULFUR AND AROMATICS

o   Standard hydrotreating can reduce sulfur levels by 85% to 95%, but would have little impact on aromatics.

o   Conventional hydro-refining can reduce sulfur levels by up to 95% and aromatics by 15% to 30%.

o   Two-stage hydro-processing can reduce diesel aromatics levels by up to 70%.

o   Mobil's MOGD process can produce low-sulfur, low-aromatics diesel.

o   Both two-stage hydro-processing and Mobil's MOGD process can be commercially available by early to the mid-1990s.

C. OPTIONS FOR REDUCING GASOLINE AROMATICS

o   Isomerization, MTBE, etherol, and BTX extraction are attractive options.

D. LEVEL OF ACCURACY OF CAPITAL COSTS

o   The level of accuracy of capital costs for conventional commercial processes is about ±25-30%.

o   The level of accuracy of capital costs for developing processes, such as two-stage hydroprocessing and the MOGD process, is about ±40-50%.

E.   DIESEL SULFUR AND AROMATICS REDUCTION

o   Little new capacity is justified in 1991, based on current quality restrictions.

o   Lowest attainable diesel sulfur level without investment is 0.19% for high-sulfur diesel and 0.14% for total California diesel.

o   Diesel aromatics can be reduced by only 5 to 14% of base levels without investment.

o   Diesel sulfur levels can be reduced to 0.05% sulfur with investment.

o   Controlling diesel sulfur at 0.05% reduces diesel aromatic levels by only 1.3%.

o   Costs to reduce diesel sulfur to 0.05% are about 6¢/gallon and investment requirements are about $0.3 billion.

o   Diesel aromatics can be reduced to 10% with new process capacity.

o   Most diesel will meet 0.05% sulfur if reduced to 10% aromatics.

o   Costs to reduce diesel aromatics increase from about 4¢/gallon for 20% aromatics to 8¢/gallon for 15% aromatics and 28¢/gallon for 10% aromatics. Investment requirements are $0.4, $0.9 and $1.5 billion, respectively.

o   Costs are significantly higher for small, simple topping and hydroskimming refineries.

o   Use of low-sulfur/low-aromatics diesel blendstocks dramatically reduces costs, but it is uncertain whether these blendstocks will be available at diesel prices.

o   Control of only segregated diesel will reduce control costs but increase levels of overall sulfur and aromatics;

o   If new hydrogen plant capacity is required to support all new hydroprocessing units, costs of diesel sulfur and aromatics reduction will increase about 10 to 20%.

o   An increase in methanol prices to 70¢/gallon eliminates the MOGD process route for aromatics levels of 20 and 15%. For aromatics levels of 10%, the MOGD process is still utilized and costs increase proportionately with the price of methanol.

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o   Control costs will increase in the future, because of increased refinery utilization, diesel demand, and energy price.

E.   GASOLINE AROMATICS REDUCTION

o   California gasoline aromatics can be reduced by only about 1% of base levels while maintaining base case octanes without process investment.

o   Gasoline aromatics can be reduced by 5% to 20% of base levels while maintaining base case octane with process investment.

o   Maximum California aromatics reduction with process investment is 18.1% of base level aromatics, or from 31.5% to 25.8%.

o   Costs to reduce gasoline aromatics to 25.8% are about 7¢/gallon and investment requirements are about $1.4 billion.

o   Costs per gallon are significantly higher for small, simple hydroskimming refineries.

o   Costs of gasoline aromatics reduction will decrease dramatically with the use of purchased high-octane/low-aromatics blendstocks, but availability of these blendstocks at gasoline blending value is uncertain.

o   With increase in the price of methanol to 70¢/gallon, MTBE capacity is largely replaced by isomerization at a slight increase in cost.

o   Refiners will not be able to make gasoline demand, grade split, and octane without substantial investment in 1995.

o   Costs for gasoline aromatics reduction cases were higher in 1995 versus 1991, because of increased gasoline octane, increased gasoline and diesel demand, and increased energy (crude oil) costs.

o   Aromatics levels could be reduced by only 15% in 1995 versus 18% in 1991 because of increased gasoline octane requirements.

o   Aromatics levels can be reduced by 25 to 70% depending on the refinery group with unlimited purchase of high-octane, low-aromatics blendstocks.

o   Costs will continue to increase and the level of aromatics reduction will decrease beyond 1995 because of increased gasoline octane requirements, refinery utilization, gasoline demand and energy price.

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E. IMPACT ON REFINERY EMISSIONS

o   Refinery emissions will decline for diesel sulfur reduction because of decreased FCC utilization and increased FCC feed desulfurization.

o   Refinery emissions will increase for diesel aromatics reduction because of increased downstream processing.

o   All refinery emissions will increase, except for SO_x, for gasoline aromatics reduction because of increased downstream processing. SO_x emissions will decrease because of decreased FCC utilization.

F. IMPACT OF FUEL QUALITY ON AUTOMOTIVE PERFORMANCE AND EMISSIONS

o   Lower diesel fuel sulfur levels, lower aromatics content, and higher cetane number will improve automotive performance.

o   Higher cetane will more than offset lower diesel heating value and result in increased fuel efficiency in new lower compression ratio engines.

o   Projected changes in gasoline quality will have little impact on automotive performance.

o   Reduction of diesel sulfur will lead to a proportional decrease in SO_x exhaust emissions and a reduction in particulate emissions.

o   Reduction of diesel aromatics content will directly reduce evaporative emissions and will reduce exhaust emissions as a result of improved combustion efficiency.

G. RECOMMENDATIONS FOR FUTURE STUDIES

o   Analysis of the refining cost of reducing diesel aromatics levels to 20% and 15% along with diesel sulfur levels to 0.05%.

o   Analysis of the cost of reducing the content of benzene in gasoline.

H. IMPLICATIONS FOR ARB REGULATORY PROGRAM

This study provides an analysis of the refining costs necessary to improve motor vehicle fuel quality to various levels. The ARB is independently investigating the impact of fuel quality on emissions from vehicular sources. The results of these two studies can be combined to determine the cost of reducing vehicular emissions through refining improvements in motor vehicle fuel quality.

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III. METHODOLOGY AND STUDY RESULTS

A. METHODOLOGY

1. Development of Refinery Cost Model

In 1986, there were 30 operating refineries in California, each with a slightly different configuration. These variations led to the use of different options to achieve more restrictive product qualities. To analyze these differences and the costs associated with them, we divided the 30 operating California refineries into 6 groups.

We obtained information about the operation of California refineries through a confidential refinery survey.

Based on the survey information, we selected the following refineries for modeling in each refinery group:

Group	Description	Refinery/Location
I	Topping	Not modeled[*]
II	Hydroskimming	Kern Oil-Bakersfield
III	Conversion	Unocal - Los Angeles
IV	Deep Conversion - w/o hydrocracking	Shell - Wilmington
V	Deep Conversion - LA Basin	ARCO - Carson
VI	Deep Conversion - Northern CA	Exxon - Benicia

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[*] Since topping refineries generally do not produce gasoline and produce only a small volume of diesel, we chose not to model this refinery type. We estimated the costs for this refinery type outside the LP model.

In addition to the refinery survey data, we obtained additional information about 1986 refinery operation from other sources . The California Energy Commission provided valuable statistics on refinery input and output for the refinery groups selected for 1986. Reports and studies from state and federal agencies provided information that proved particularly useful in identifying current diesel sulfur and aromatics content and gasoline aromatics content.

LP models were developed for each selected refinery, based on refinery survey information. Each model was calibrated by comparing results against actual refinery operating data for 1986. We then scaled up the data obtained from the refinery surveys and LP modeling work for the entire state. We compared scaled up model results with the volumes of refinery input and output obtained from the surveys and

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with the CEC data. We scaled up the diesel and gasoline qualities from the survey and LP model results in proportion to product volume. We compared the overall diesel and gasoline qualities to published surveys by the NPRA (National Petroleum Refiner's Association) and CARB, respectively, and we found the scaled-up results we had obtained to be reasonable when compared to these published sources.

2.   Basis of Study

The required periods of analysis for this study were 1991 and 1995. We selected the November 1987 California Energy Commissions "Fuels Report" as the basis for refinery input and refined product output. We chose this report as a baseline, because it was a published survey that had been reviewed by the industry, and it contained complete and consistent energy and price forecasts.

We based the price of Alaskan North Slope (ANS) crude (marginal crude oil) and feedstocks (i.e., natural gas, butane, and methanol) used by the LP model on the CEC forecast, and we valued gasoline and diesel feedstacks as blending components.

The only refined products that we valued in this study were LPG, petroleum coke, and BTX. We price these products because their level of production was not limited. We ran all other prime products, crude oils other than ANS, and feedstocks, such as vacuum gas oil, as fixed volumes in the LP model. Prices were therefore not required for these materials.

3.   Selection of Process Technology

a.   Options for Reducing Diesel Sulfur and Aromatics

Options for reducing diesel sulfur and aromatics fall into three general categories:

o   Existing process equipment

o   Additions to process capacity; and

o   Non-process options.

Short-term options with existing capacity include changes in kerosene/diesel cutpoint, full utilization of existing hydroprocessing capacity, increases in hydroprocessing severity, and upgrading of hydroprocessing catalyst.

Possible additions to process capacity include:

o   Low-severity distillate hydrotreating;

o   Moderate-severity distillate hydrorefining;

o   Noble metal catalyst distillate hydro-dearomatization;

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o   High-severity hydrorefining/mild hydrocracking;

o   Hydrogen production;

o   Aromatics extraction;

o   Mobil methanol-to-olefins (MTO) process to produce mixed light olefins; and

o   Mobil olefins to gasoline and distillate (MOGD) process to convert refinery or MTO olefins to low-aromatics, high-cetane distillate.

Non-process options include segregation of No. 2 fuel and diesel products (so that only diesel stocks have to be improved) and purchase of low-aromatics/low-sulfur blendstocks from outside California.

The diesel hydro-dearomatization process currently is not commercially available, but it has operated successfully on kerosene feed in a number of commercial units. Similarly, there are no current commercial Mobil synthetic diesel process units, but the process is similar to the commercially available Mobil methanol-to-gasoline (MTG) process and has been tested in a semi-commercial size unit. However, in our opinion both processes could be made commercially available by the early to mid-1990s if reduction of diesel aromatics is mandated on a state or national level.

b.   Options for Reducing Gasoline Aromatics

Whereas the reduction of diesel sulfur and aromatics will improve the diesel cetane number, reduction of gasoline aromatics reduces gasoline octane. A major assumption in this study was that gasoline octanes would have to be maintained at projected base case levels, and any octanes lost through aromatics reduction would have to be replaced. In addition, gasoline volatility may be reduced by EPA legislation in the near future. Thus, process options to reduce gasoline aromatics cannot be considered without also considering their impact on gasoline octane and volatility.

Options to reduce gasoline aromatics fall into three general categories:

o   Existing process equipment;

o   New or modified process equipment; and

o   Blending.

Options to reduce gasoline aromatics with existing processing equipment include modification of product cut points, reduced severity on catalytic reforming, reduced cat cracking severity, full utilization of aromatics extraction capacity, and increased

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utilization of light-naphtha isomerization, alkylation, and catalytic polymerization (cat poly) capacity.

New conventional process options considered to reduce gasoline aromatics include:

o   Reformer modifications and new continuous reforming;

o   BTX extraction from reformate and light FCC gasoline;

o   Alkylation, catalytic polymerization, and dimerization;

o   Isomerization;

o   MTBE production; and

o   Etherol production.

Many of these conventional technologies do not directly remove aromatics, but they can decrease gasoline pool aromatics content through the blending of low-aromatics content streams, and they will replace octanes lost because of declines in reformer severity and aromatics extraction.

All of the above process options were available in our LP model analysis at standard process costs. The use of catalytic polymerization and dimersol was limited to prevent increase of gasoline olefins content.

4.   Cost of Reducing Diesel Sulfur, Diesel Aromatics and Gasoline Aromatics

a.   Approach

We applied common methodology to estimate the refinery costs to reduce aromatics levels in diesel fuel, reduce aromatics levels in gasoline, and reduce sulfur levels in diesel fuel. We analyzed each case separately, however, to determine the refining cost of reducing each contaminant level in each motor vehicle fuel. In each case, we maintained all primary product volumes such that losses in product volume caused by aromatics removal, sulfur removal, changes in processing severity, etc., were compensated either through increased crude oil processed or purchase of outside feedstocks.

We analyzed cases both with and without allowing the purchase of outside feedstocks. Outside feedstocks that we considered included:

o   Oxygenates (MTBE and ethanol);

o   Gasoline blendstocks (alkylate and isomerate); and

o   Distillate blendstocks (low-sulfur distillate).

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To estimate the net feedstock cost impact, we developed prices for each of these feedstocks and for BTX product that were consistent with the underlying crude oil and product price forecasts. Net feedstock cost was the sum of crude oil and outside feedstock costs less credits for aromatics removed.

The only change we permitted in crude oil slate was in the volume of the marginal ANS crude oil processed. We fixed all other crude oil inputs to levels determined in the base case analysis.

For each case, we estimated the change in net feedstock costs, variable costs, fixed costs and capital costs (new investment cases only) to reduce contaminant levels relative to the base case for the modeled refinery. The cost components provided equations that the ARB can use to update or extend the results of this analysis.

b.   Diesel Sulfur and Aromatics Reduction

For the diesel analysis, we modeled low sulfur, high sulfur and military diesel separately as appropriate in each selected refinery. We included an additional "uncontrolled" distillate category in each refinery selected for our analysis of diesel and other distillate segregation sensitivity.

We analyzed cases for the reduction of diesel sulfur and aromatics both with and without new process investment. In the sulfur reduction analysis, total California costs include those costs for reducing high-sulfur diesel and exclude refineries at or below each prescribed sulfur level. The average diesel sulfur level attained and costs per gallon are expressed in terms of total California diesel produced, including current production of low sulfur diesel. In the aromatics reduction analysis, we reduced aromatics levels of both high-sulfur and low-sulfur diesel.

c.   Gasoline Aromatics Reduction

For the gasoline analysis, we modeled each grade of gasoline separately based on the estimated grade split for each selected refinery, and we controlled aromatics levels on the overall gasoline pool.

We analyzed cases for reduction of gasoline aromatics both with and without new process investment. The average gasoline aromatics reduction and costs per gallon are expressed in terms of total California gasoline produced.

B.   STUDY RESULTS

1.   Costs of Reducing Diesel Sulfur and Aromatics

a.   Diesel Sulfur and Aromatics Reduction without New Process
     Investment

In the first series of cases analyzed, we progressively reduced
high-sulfur diesel levels from the base case to 0.25%, 0.20% and the
maximum extent possible without new process investment.

High-sulfur diesel could be reduced to 0.25% sulfur in all refinery
groups without investment. Costs averaged 1.3 ¢/gallon for 178 MB/D
of high sulfur diesel and 0.8 ¢/gallon of total California diesel.
Including the effect of current low-sulfur diesel, the average sulfur
level dropped from 0.27% in the base case to 0.17%.

The minimum sulfur concentration attainable in high-sulfur diesel
without process investment varied from 0.21% in Groups III and VI to
0.20% in Group V and 0.10% in Groups I and II. This resulted in an
average attainable sulfur level of 0.19% for high-sulfur diesel and
0.14% for total California diesel. Total diesel aromatics levels
decreased slightly from 30.7% in the base case to 29.2%, because of
the increased utilization of existing hydrotreating and hydrorefining
capacity to reduce sulfur levels. Cetane number increased slightly
from 43.7 to 44.4, along with the decrease in aromatics content.

Cost of maximum sulfur reduction without investment varied from 3.3
¢/gallon in Group V to 18.4 ¢/gallon in Group I and averaged 7.7
¢/gallon of high-sulfur diesel, or 5.0 ¢/gallon of total California
diesel. Costs were by far the highest in small topping refineries
which have few options to reduce diesel sulfur without investment.

In the next series of cases, we successively decreased both high and
low-sulfur diesel aromatics levels by a nominal 5%, 10% and to the
maximum extent possible from base case aromatics levels without new
process investment. Since existing California hydroprocessing
capacity was designed for diesel sulfur removal only and has limited
capability to reduce diesel aromatics levels, it was possible to
reduce aromatics by only a nominal amount in all refinery groups
without investment. Maximum aromatics reduction without investment
varied from 5% in Group VI to 14% in Groups I and II and averaged 8.7%
of base aromatics levels, or an absolute reduction from 30.7 to 27.9%.
Cost for maximum aromatics reduction averaged 14.3 ¢/gallon, but was
60 ¢/gallon in Groups I and II, which have little capability to reduce
diesel aromatics without investment. Diesel sulfur level was reduced
to 0.20% and cetane increased to 44.4 with 8.7% aromatics reduction.

b.   Diesel Sulfur and Aromatics Reduction with New Process Investment

We analyzed the following seven cases to determine refinery process
requirements and costs for reducing diesel sulfur and aromatics:

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o   Reduction of diesel sulfur level to 0.15 wt%;

o   Reduction of diesel sulfur level to 0.05 wt%;

o   Reduction of diesel aromatics level to 20 vol%;

o   Reduction of diesel aromatics level to 15 vol%;

o   Reduction of diesel aromatics level to 10 vol%;

o   Reduction of both diesel sulfur level to 0.05 wt% and aromatics
    level to 10 vol%; and

o   Reduction of diesel sulfur level to 0.05 wt% and aromatics level
    to 10 vol%, allowing purchase of low-sulfur, low-aromatics diesel
    blendstocks.

The 1991 costs of reducing diesel sulfur level with new process
investment are shown in Figure I. Costs are shown separately for
small, simple Group I and II refineries; for larger, more complex
Group III-VI refineries; and for total California.

Costs for reduction of diesel sulfur to 0.15 wt% averaged 1.9 ¢/gallon
for California. Costs were 1.0 ¢/gallon for Group III-VI refineries,
but were 7.8 ¢/gallon for Group I and II refineries, because of higher
initial sulfur levels and little existing hydroprocessing capacity.
Total investment requirements were $96 million for 34 MB/D of new
hydroprocessing capacity.

All refineries modeled were able to reduce diesel sulfur levels to
0.05% with new process investment. Costs averaged 6.3 ¢/gallon of
total California diesel, but varied from 1.9 ¢/gallon for Group III-VI
refineries to 34.7 ¢/gallon for Group I and II refineries. Process
investment requirements were $266 million for 112 MB/D of
hydroprocessing investment. Total aromatics levels were reduced
slightly from 30.7% in the base case to 29.4% in the maximum sulfur
reduction case, because of partial aromatics saturation in
hydroprocessing units. Cetane levels also increased from 43.7 in the
base case to 44.9.

The costs for reducing diesel aromatics level with new process
investment are shown on Figure II. Costs for reduction of diesel
aromatics to 20% averaged 3.8 ¢/gallon for California. Costs were
5.2 ¢/gallon for Group I and II refineries and 3.6 ¢/gallon for Groups
III-VI refineries. Costs for reducing aromatics to 20% for Group I
and II refineries were lower than costs for reducing sulfur to
0.05 wt%, because of the high initial sulfur levels in these
refineries. Costs for reducing aromatics to 20% for Group III-VI
refineries were higher than costs for reducing sulfur to 0.05 wt%
because of the higher severity hydroprocessing required to achieve
aromatics reduction. Total investment requirements for reduction to
20% aromatics were $410 million for 162 MB/D of new hydroprocessing
investment.

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Figure I
1991 Costs of Reducing Diesel Sulfur

Investment
Millions $:

| 13 | 83 | 96 | | 62 | 204 | 266 |

COST: cents/gal Diesel

Legend:
- Groups I & II
- Groups III – VI
- Total California

.15% Sulfur: 7.8, 1.0, 1.9

.05% Sulfur: 34.7, 1.9, 6.3

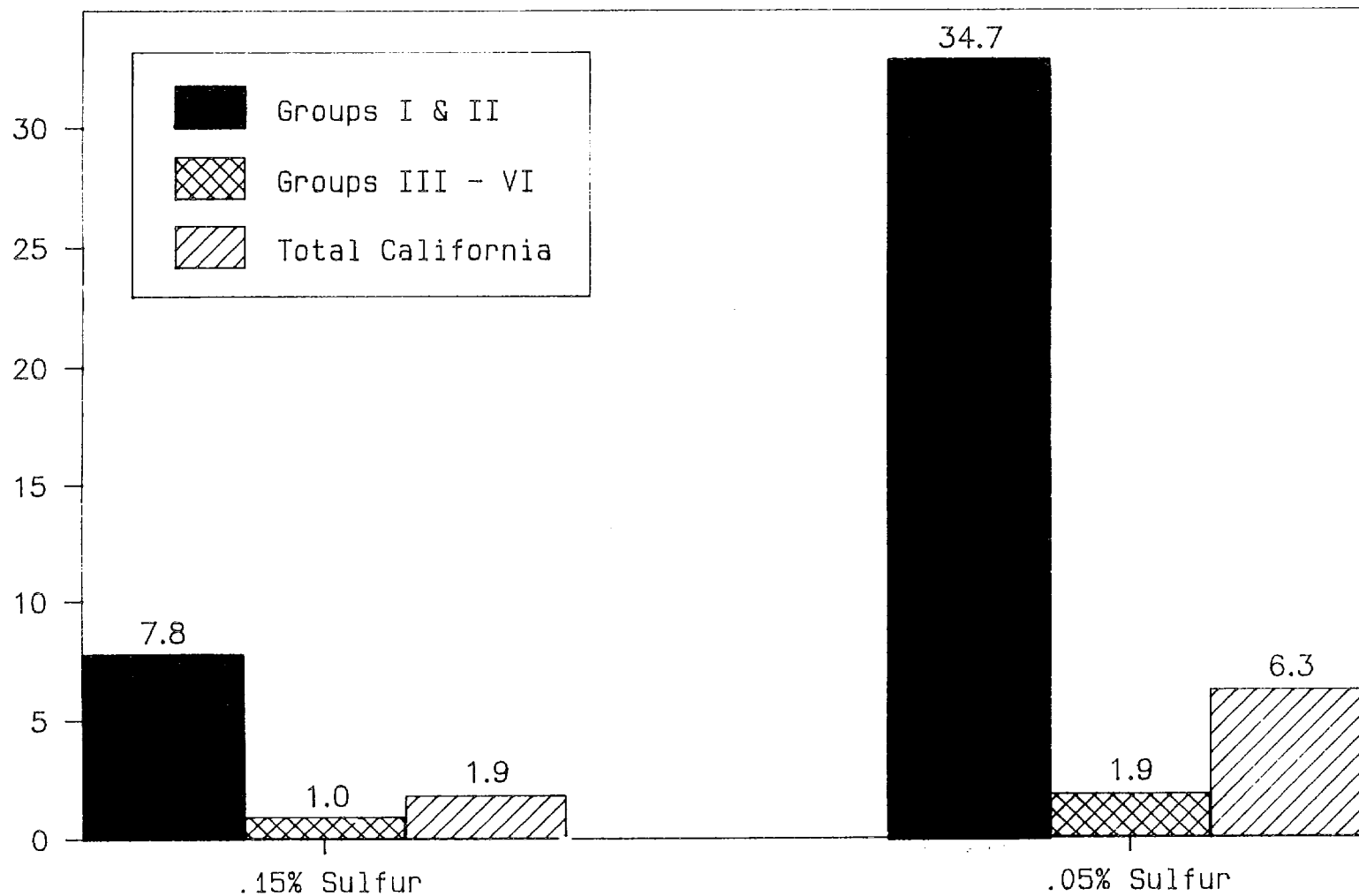# Figure II
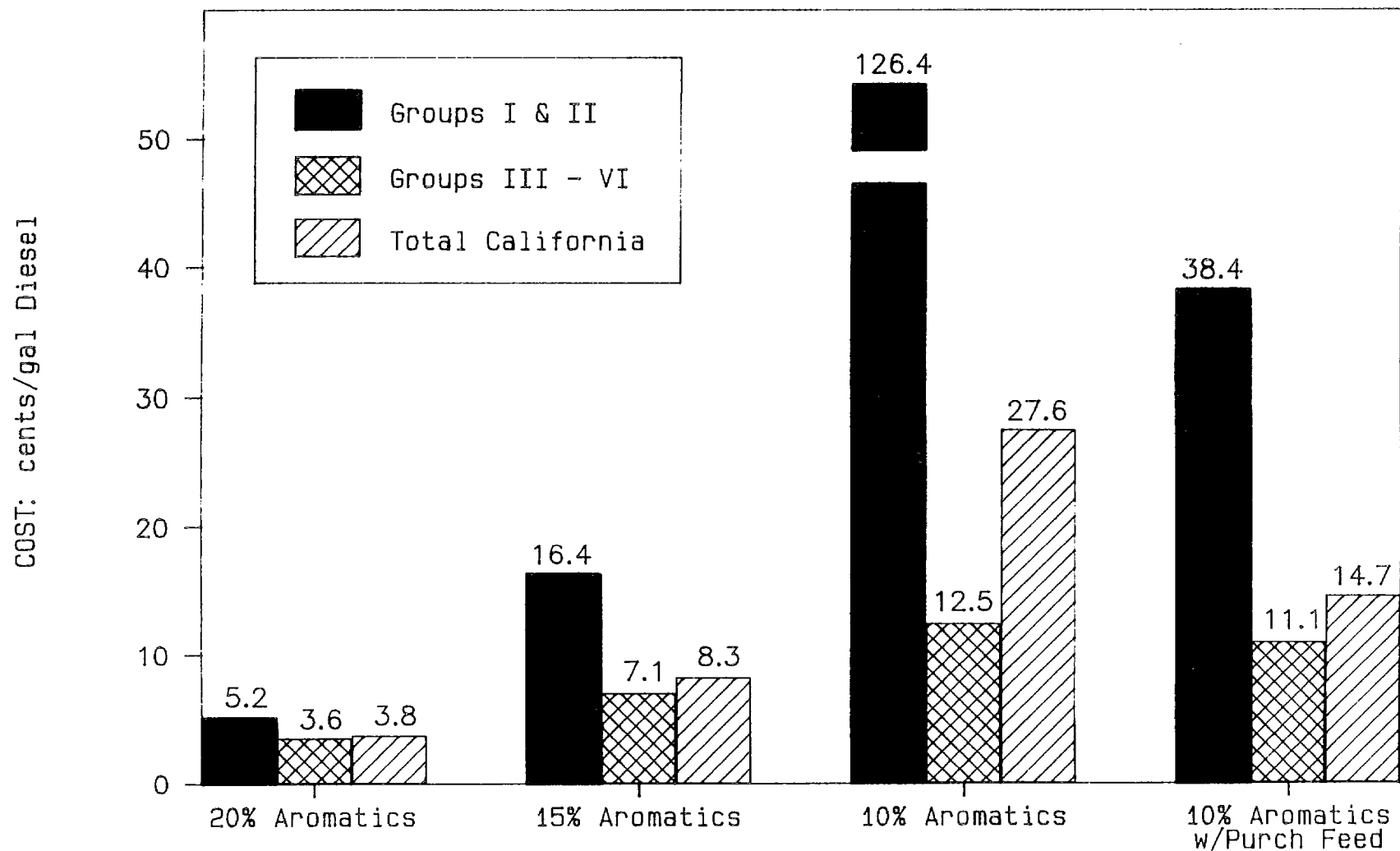## 1991 Costs of Reducing Diesel Aromatics

Investment
Millions $:   106 304 410   309 555 864   514 917 1431   362 738 1101

Costs to reduce diesel aromatics to 15% increased to 8.3 ¢/gallon. Costs were 16.5 ¢/gallon for Group I and II refineries and 7.1 ¢/gallon for Group III-VI refineries. Investment costs were $864 million for 330 MB/D hydroprocessing and 17 MB/D of Mobil synthetic diesel. Sulfur levels were reduced to an average of 0.05 wt% and the cetane level increased to 49.9.

Costs to reduce diesel aromatics to 10% increased to 27.6 ¢/gallon. Costs were 126.4 ¢/gallon for Group I and II refineries and 12.5 ¢/gallon for Group III-VI refineries. Investment costs increased to $1.4 billion for 380 MB/D of hydroprocessing, 105 MM SCF/D hydrogen production and 55 MB/D of Mobil synthetic diesel processing. Diesel sulfur was reduced to an average of 0.03% and cetane increased to 50.9.

Diesel sulfur levels were below 0.05% in the 10% aromatics case except for Group VI which was at 0.07%. We analyzed an additional case with Group VI at both 10% aromatics and 0.05% sulfur which increased total California costs slightly. Results for this case are shown in the main body of the report.

The availability of low-sulfur/low-aromatics diesel blendstocks at projected 1991 diesel price had a dramatic impact on the cost of reducing diesel sulfur and aromatics levels. Costs decreased by nearly 50% to an average of 14.7 ¢/gallon. Costs in Groups I and II decreased even more dramatically -- from 126.5 ¢/gallon to 38.4 ¢/gallon. Costs for Groups III-VI dropped to 11.1 ¢/gallon and investment costs dropped by $350 million to $1.1 billion.

Although the cost of aromatics reduction in diesel was significantly lower with purchased low-aromatics/low-sulfur feedstock, the analysis is based on the assumption that these feedstocks would be available at the price of diesel. It is uncertain if these feedstocks would be available -- particularly if a reduction of diesel aromatics is mandated in other U.S. regions.

c. Impact of Diesel Segregation

In the base diesel analysis performed in this study, we assumed zero percent segregation; that is, all diesel was required to meet the same restrictive quality requirements. Two sensitivities were analyzed controlling only a portion of the diesel fuel based on the 1986 NPRA survey level of diesel segregation and based on a 50% diesel segregation.

Total California costs for 0.05% sulfur diesel were reduced by 1.0 ¢/gallon in the NPRA segregation case and 5.1 ¢/gallon in the 50% segregation case. However, since a lower volume of diesel was controlled, average California diesel sulfur levels were reduced only to 0.12% in the NPRA segregation case and 0.17% in the 50% segregation case versus 0.05% when all diesel was controlled.

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Similarly, total California costs for 10% aromatics and 0.05% sulfur diesel were reduced by 6.1 ¢/gallon in the NPRA segregation case and 13.3 ¢/gallon in the 50% segregation case. The average California diesel aromatics level was reduced only to 21% in the NPRA segregation case and to 20% in the 50% segregation case versus 10% when all diesel was controlled.

d.   Impact of Hydrogen Plant Capacity on Diesel Costs

The LP solutions derived during this study generally indicated little need for new hydrogen plant capacity, except in Group I and II refineries. While we feel that an assumption that new hydrogen plant capacity is required to support every new hydroprocessing project is too conservative, our results may be too optimistic. We have therefore estimated hydrogen plant costs to support new hydroprocessing capacity selected in our analysis as shown on Figure III. The hydrogen plant costs shown are in addition to hydrogen plant requirements based on the LP model study results.

Additional hydrogen plant requirements to reduce diesel sulfur levels to 0.05 wt% would increase investment costs $78 million, or 0.5 ¢/gallon of diesel. Additional hydrogen plant requirements to reduce diesel aromatics increase by 137 million to $209 million, and unit costs would increase by 1.1 to 1.5 ¢/gallon of diesel.

e.   Impact of Methanol Prices on Diesel Costs

Mobil's MOGD process was selected in some refinery groups for reduction of diesel aromatics. With an increase in methanol price to 70 ¢/gallon, the MOGD process was replaced in the 15% aromatics case by new hydroprocessing capacity at an 85% increase in costs. For aromatics levels of 10%, the MOGD process was still fully utilized and costs doubled. The cost increase was nearly proportional to the increase in the price of methanol.

f.   1995 Diesel Analysis

We also examined cost impacts from reducing diesel sulfur and aromatics in 1995 versus 1991. Costs were higher in 1995 because of increased refinery utilization, diesel demand, and increased energy (crude oil) costs.

Total costs to reach 0.05% sulfur increased from 6.3 ¢/gallon in 1991 to 7.7 ¢/gallon in 1995. Investment costs (in constant 1987 dollars) increased from $266 million to $291 million, and total annual costs increased from $280 million to $363 million.

Total costs to reach 20% aromatics increased from 3.8 ¢/gallon in 1991 to 4.0 ¢/gallon in 1995. Investment costs were nearly constant at about $410 million and total annual costs increased from $170 million to $190 million.

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Figure III
Impact of Hydrogen Plant Capacity on Diesel Costs

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Investment Millions \$:						
Base	96	266	410	864	1431	1101
H2	35	78	137	175	209	198
Total	131	344	547	1039	1640	1299

COST: cents/gal Diesel

Legend:
- ■ Base Results
- ▨ Additional H2 Plant

Values above bars: 2.1, 6.8, 4.9, 9.5, 29.1, 16.1

X-axis categories: .15% Sulfur, .05% Sulfur, 20% Aromatics, 15% Aromatics, 10% Aromatics, 10% Aromatics w/Purch Feed

Costs to reach 15% aromatics versus 20% aromatics in 1995 more than doubled to 8.6 ¢/gallon at an annual cost of $405 million. Investment requirements were $850 million.

As in 1991, costs increased significantly to reach 10% aromatics. Total costs were 33.5 ¢/gallon or $1.6 billion per year, and investment requirements were $1.6 billion.

We expect costs of diesel sulfur and aromatics reduction to continue to increase beyond 1995, because of increased refinery utilization, diesel demand, and energy costs.

2.   Cost of Reducing Gasoline Aromatics

a.   Gasoline Aromatics Reduction without New Process Investment

Aromatics levels were first reduced from the base case level in selected refineries to the maximum extent possible without new process investment. In all aromatics reduction cases, gasoline octanes were maintained at base case 1991 levels.

California gasoline aromatics can be reduced only 1.0 to 4.7%[2] without new process investment because of octane constraints. Total costs averaged 3.1 ¢/gallon of gasoline, but were 62 ¢/gallon in Group II hydroskimming refineries. Benzene levels decreased along with the aromatics level, from 1.97% in the base case to 1.89%[3]

b.   Gasoline Aromatics Reduction with New Process Investment

We developed refinery costs and process requirements to reduce gasoline aromatics content for the following five cases:

o   5% aromatics reduction in 1991;

o   Maximum aromatics reduction in 1991 without purchased feedstocks;

o   18% aromatics reduction in 1991 with purchased feedstocks;

o   Maximum (15%) aromatics reduction in 1995 without purchased feedstocks; and

o   Maximum % aromatics reduction in 1995 with purchased feedstocks.

_____

[2]
    Note: In all gasoline aromatics reduction cases, results are expressed as a % reduction from the base case level rather than the absolute reduction in pool level.

[3]
    The accuracy of benzene levels is estimated at 0.1%. Results are reported to a level of 0.01% to show the difference between cases.

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All refinery groups were able to reduce gasoline aromatics by a nominal 5% from base case levels in 1991 with new process investment. Benzene levels were reduced from 1.80% to 1.75%. Total costs averaged 0.7 ¢/gallon of gasoline. However, costs were much higher for simple Group II hydroskimming refineries at 15.7 ¢/gallon. Investment requirements were $129 million for 103 MB/D of isomerization, MTBE, and etherol capacity.

Reduction of gasoline aromatics is severely limited by refinery octane constraints. Reduction of aromatics in Group II was limited to about 5%. Groups III and IV were limited to a nominal 15% aromatics reduction. It was possible to reduce aromatics levels in the most complex Group V and VI refineries by about 20% of base case levels.

The costs for maximum reduction of gasoline aromatics with new process investment are shown on Figure IV.

The maximum gasoline aromatics reduction possible in California in 1991, with new process investment, was 18.1% for reduction to an absolute level of 25.8%. Benzene levels were reduced to 1.54%. Total costs for maximum aromatics reduction averaged 7.0 ¢/gallon, but were 15.7 ¢/gallon in Group II refineries. Investment requirements were $1.4 billion for about 756 MB/D of isomerization, MTBE, etherol, BTX extraction, and hydrogen plant capacity. BTX sales volumes were 28 MB/D for an aromatics reduction in gasoline of 47 MB/D.

The maximum aromatics reduction case with investment was repeated allowing purchase of MTBE, ethanol, isomerate and alkylate at gasoline blending value. A total of 31 MB/D MTBE and 2 MB/D alkylate were purchased and had a dramatic impact on refining costs. Average costs dropped to 1.8 ¢/gallon. Investment requirements dropped to $237 million for 120 MB/D of isomerization, MTBE, etherol and BTX extraction capacity. Costs for reduction of aromatics in Group II were _lower_ than the base case because of the availability of low-aromatics feedstocks.

Although costs of aromatics reduction were considerably lower with purchased low-aromatics feedstocks, we based our analysis on the assumption that these blendstocks would be available at projected gasoline blending value. It is uncertain if low-aromatics blendstocks will be available at blending value--particularly if reduction of gasoline aromatics is mandated in other U.S. regions.

Refineries will not be able to make 1995 gasoline demand, grade split and octanes without substantial investment. Gasoline demand is forecast to increase by 7.0 MB/D, or 0.8%, between 1991 and 1995. More significantly, because of increased unleaded premium and unleaded intermediate demand, gasoline pool octane is forecast to increase from 88.3 to 89.0 (R+M)/2. With this significant increase in octane requirements, $236 million worth of new process investment was justified in the base case without any reduction in gasoline aromatics.
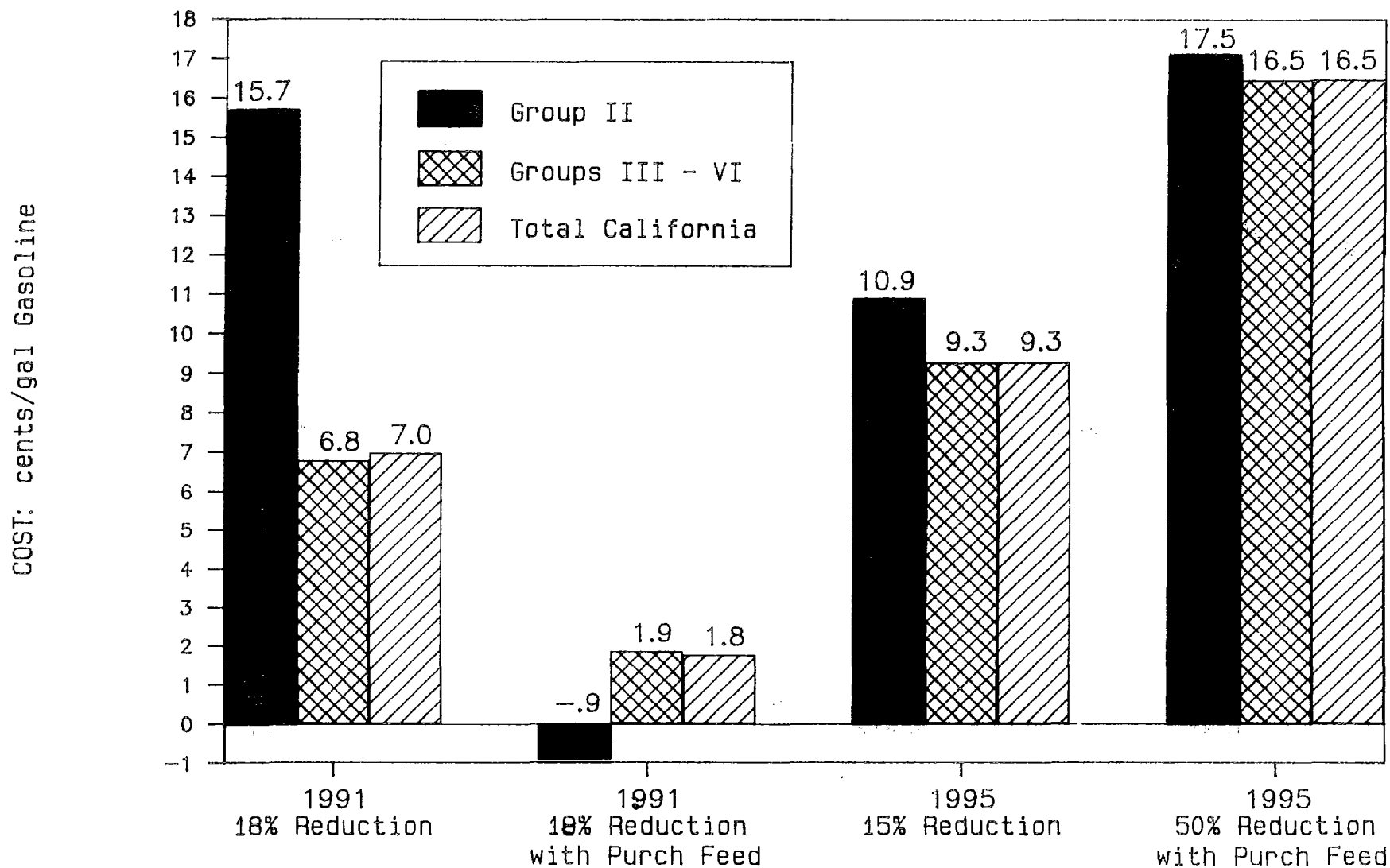
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Figure IV
Costs of Reducing Gasoline Aromatics

Investment
Millions $:   56   1379 1435   .3   236.4 236.7   47 1808 1855   15 1251 1266

COST: cents/gal Gasoline

Legend:
- Group II
- Groups III – VI
- Total California

1991
18% Reduction

1991
18% Reduction
with Purch Feed

1995
15% Reduction

1995
50% Reduction
with Purch Feed

Values shown on bars:
- 1991 18% Reduction: 15.7, 6.8, 7.0
- 1991 18% Reduction with Purch Feed: -.9, 1.9, 1.8
- 1995 15% Reduction: 10.9, 9.3, 9.3
- 1995 50% Reduction with Purch Feed: 17.5, 16.5, 16.5

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The maximum aromatics reduction possible in 1995 averaged 14.7% to an absolute level of 27.5% aromatics. Benzene level was reduced to an average of 1.61%.

Aromatics reduction was lower and absolute aromatics levels were higher in 1995 because of higher pool octane requirements than in 1991. Average costs for 14.7% aromatics reduction in 1995 were 9.3 ¢/gallon versus 7.0 ¢/gallon for 18.1% reduction in 1991. Thus, costs were _higher_ in 1995 for _less_ reduction because of higher octane requirements.

Investment requirements in 1995 were $1.9 billion for maximum gasoline aromatics reduction versus $1.4 billion in 1991. More than 1,150 MB/D of new processing was required, including isomerization, MTBE, etherol, BTX extraction and hydrogen plant capacity. BTX sales volumes were 30 MB/D for an aromatics reduction in gasoline of 40 MB/D.

The maximum gasoline aromatics reduction in 1995 with purchased feedstocks available averaged 50% to an absolute level of 16.1%. Benzene level was reduced to an average of 1.61%. Costs averaged 16.5 ¢/gallon and were similar in all refinery groups. Investment requirements were $1.3 billion for 700 MB/D isomerization, MTBE, BTX extraction, and hydrogen plant capacity. Purchased blendstock requirements included 109 MB/D alkylate, 62 MB/D MTBE, and 8 MB/D ethanol.

The maximum gasoline aromatics reduction possible in 1995 by refinery group, both with and without purchased feedstocks, is shown in Figure V.

Maximum aromatics reduction without purchased feedstock varied from 5% in Group II to 17% in Groups V and VI and averaged 14.7% Maximum aromatics reduction with purchased feedstocks varied from 24% in Group IV to 67% in Group II and averaged 50.3%.

While gasoline aromatics can be reduced significantly with purchased feedstocks, it is uncertain if the level of feedstocks necessary would be available in the future.
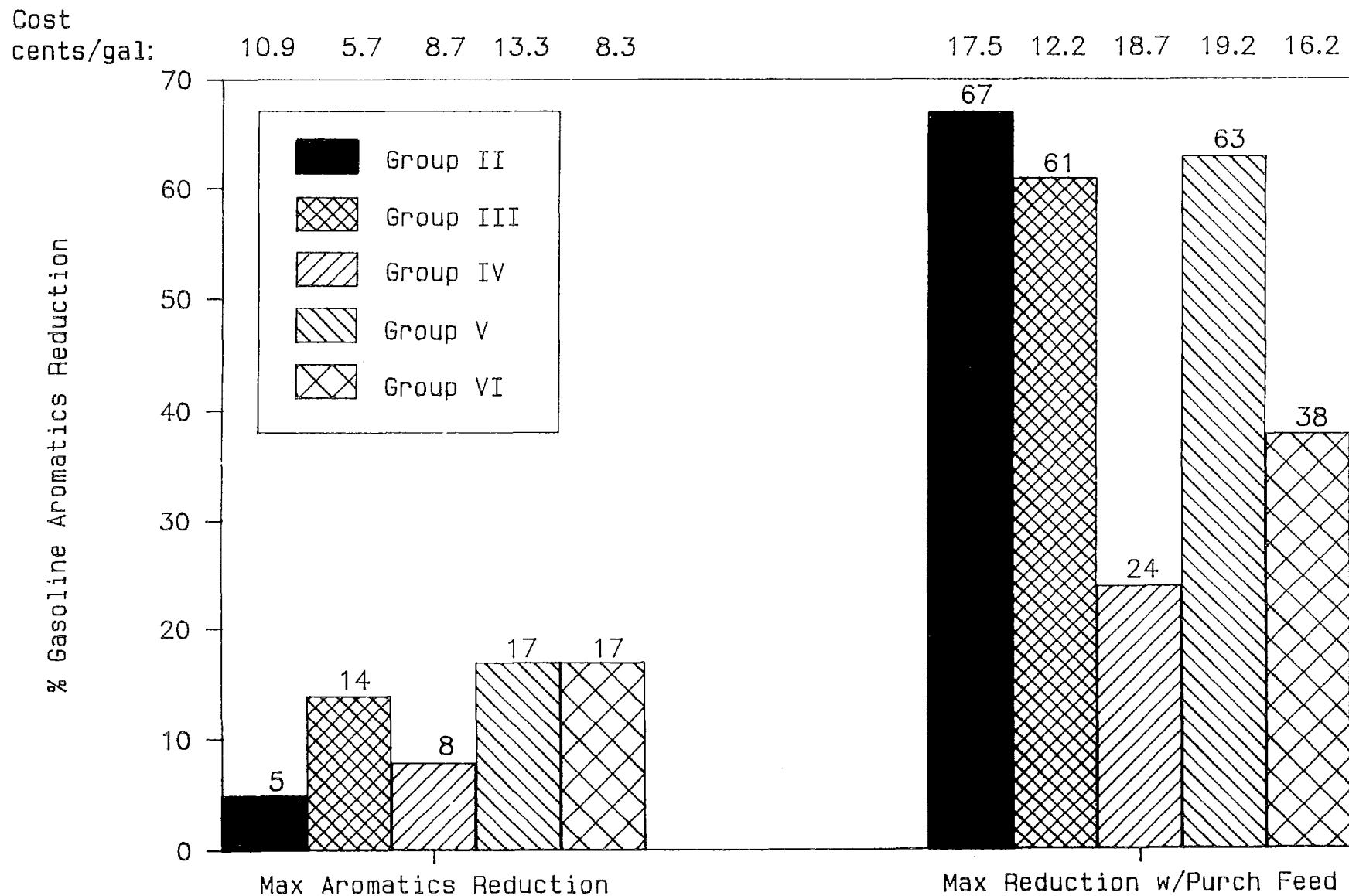
We would expect costs to continue to increase and the level of gasoline aromatics reduction possible to decrease beyond 1995 because of increasing pool octane requirements, refinery utilization, gasoline demands, and energy costs.

c.   Impact of Methanol Prices on Gasoline Costs

We selected the MTBE and etherol processes in most cases to reduce gasoline aromatics. With an increase in methanol price to 70 ¢/gallon, about 15 to 25% of this process capacity would be replaced by isomerization and alkylation. Costs for gasoline aromatics reduction increased by about 5%.

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Figure V
1995 Maximum Gasoline Aromatics Reduction by Group

Cost
cents/gal: 10.9   5.7   8.7   13.3   8.3   17.5   12.2   18.7   19.2   16.2

3. Impact of Fuel Quality on Refinery Emissions

The reduction of sulfur and aromatics in diesel and aromatics in gasoline will have an impact on refinery emissions, because of increased crude runs, fuel consumption, downstream processing requirements, and sulfur recovery. Refinery capacity utilization and fuel consumption results from the LP model were applied to standard AP-42 industry factors to calculate the following refinery emissions for each case:

o   Nitrogen oxides (NO_x);

o   Sulfur oxides (SO_x);

o   Carbon monoxide (CO);

o   Volatile organic compounds (VOC); and

o   Particulates.

Actual California refinery emissions will be lower than our calculation using AP-42 factors; however, we are primarily concerned with the differences in emissions caused by contaminant reduction in diesel and gasoline rather than absolute emissions levels.

Total California refinery emissions will <u>decline</u> in diesel sulfur reduction cases. This will occur because of reduction in FCC utilization and increased FCC feed desulfurization (for refineries with FCC feed hydrotreating units).

For diesel aromatics reduction, refinery emissions will increase for all cases. This is attributed to increases in crude runs and downstream process utilization needed to maintain diesel production as volume is lost because of aromatics reduction. With purchased feedstocks available, emissions will decline because of reduced refinery operations.

Emission impact will be reduced with NPRA or 50% diesel segregation because of a lower volume of diesel controlled.

For the maximum gasoline aromatics reduction case, all emissions increased except SO_x because of major process additions required to reduce aromatics levels. SO_x decreased because of decreased FCC utilization as high-aromatics FCC gasoline was replaced by other blendstocks. With purchased feedstocks available, emissions will decline across the board because of reduced refinery operations.

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4.   Impact of Fuel Quality on Automotive Performance and Emissions

The major impacts on diesel fuel quality as a result of sulfur and aromatics reduction will be as follows:

o   Decrease in specific gravity (and heating value);

o   Decrease in sulfur level;

o   Increase in cetane number;

o   Decrease in total aromatics; and

o   Decrease in polycyclic aromatic hydrocarbons (PAH).

The major impacts on gasoline quality as a result of aromatics reduction will be as follows:

o   Decrease in specific gravity (and heating value);

o   Pool octane unchanged at 88.3 (R+M)/2;

o   Vapor pressure unchanged at 9.8 psi;

o   Benzene levels reduced along with total aromatics level; and

o C_7+ aromatics reduced along with total aromatics level.

Lower diesel fuel sulfur levels, lower aromatics content, and a higher cetane number will improve automotive performance. Reduction of diesel sulfur will reduce engine wear and particulate emissions. Fuel economy may be reduced slightly because of lower heating value fuel in existing diesel engines. However, the higher cetane level will more than offset lower diesel heating value and result in increased fuel efficiency in new lower compression ratio engines.

Changes in gasoline quality will have little impact on automotive performance. As a basis for our analysis, we maintained the major gasoline qualities affecting automotive performance--octane, volatility, and distillation--at base case levels. Because of the decrease in gasoline specific gravity, there would be a theoretical 2% decrease in fuel efficiency attributed to lower heating value.

Sulfur is the single most significant contributor to diesel engine particulate emissions. In addition, sulfur compounds can interfere with oxidizing catalysts in particulate trap-oxidizers making them less effective. Lower sulfur diesel fuel is essentially required to achieve heavy-duty diesel engine particulate standards in 1991 and 1995 with practical emission control devices (exclusive of particulate traps). Reduction of diesel sulfur will lead to a proportional decrease in the SO_x exhaust emission rate and a reduction in particulate emissions.

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Reduction of diesel aromatics content will directly reduce evaporative emissions and will reduce exhaust emissions as a result of improved combustion efficiency. Reduction of diesel aromatics content will reduce particulate emissions, especially under cold-start and light-load conditions.

The emission rate of individual compounds (e.g., benzene) and combustion products (e.g., sulfur dioxide) is directly proportional to the concentration in the gasoline and fuel consumption rate. Prediction of emission rates for complex mixtures of compounds is much less reliable, but emission rates would tend to increase with increased concentration of contaminants.

Reduction of gasoline benzene and aromatics content will reduce both evaporative and exhaust emissions. Polycyclic aromatic hydrocarbons (PAH) and their nitro-derivatives will also be reduced because of the reduction of PAH compounds in the fuel.

IV. RECOMMENDATIONS FOR FUTURE STUDIES

As a result of this analysis we recommend that the ARB initiate the following studies:

1. Analysis of the Refining Cost of Reducing Diesel Aromatics Levels to 20% and 15% Along with Diesel Sulfur Levels to 0.05%.

In our study, we separately analyzed the cost of reducing sulfur to .05% and aromatics to 20, 15 and 10%. In addition, we analyzed the impact of reducing diesel aromatics levels to 10%, along with diesel sulfur to 0.05%.

It is likely that costs would increase significantly to control both aromatics levels to 20% and sulfur to 0.05%. In addition, control of diesel aromatics levels to 20% and sulfur level to 0.05% is a strategy that is currently under consideration by the U.S. EPA. An analysis by the ARB with the objective of reaching the same aromatics and sulfur levels would give a direct point of comparison with the EPA results.

Although neither the U.S. EPA has not examined the costs to control diesel to both 15% aromatics and 0.05% sulfur, this case should be analyzed by the ARB if it is to be considered as a control strategy.

2. Analysis of the Cost of Reducing the Content of Benzene in Gasoline

In our study, we analyzed the refining cost impact of reducing total aromatics in gasoline and reported the impact on the benzene content of gasoline. Although benzene generally decreased along with aromatics, the rate of decrease was different.

The results of this analysis would have been significantly different if benzene rather than total gasoline aromatics had been controlled. Since benzene makes up a much smaller portion of the gasoline pool (1.85% versus 33% total aromatics), reduction of only the benzene content would have a much less dramatic effect on refinery octanes and refinery costs. Previous studies have indicated that benzene levels can be reduced by considerably more than total aromatics content.[1,2]

If the ARB is considering a control strategy to reduce benzene levels, we recommend an analysis of the cost impact on refiners to reduce gasoline benzene content.

References

[1] Arthur D. Little, Inc., "Cost of Benzene Reduction in the Petroleum Refining Industry", Report to U.S. EPA, April 1978.

[2] Arthur D. Little, Inc., "Impact on German Refiners of Removing Lead Additive Compounds and Controlling Benzene Content of Gasoline", Report to Umweltbundesamt, November 1983.

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Cost of Reducing Aromatics and Sulfur Levels
in Motor Vehicle Fuels

Acronyms

ADL	Arthur D. Little, Inc.
ANS	Alaska North Slope Crude - Marginal Crude in Alaska
ARB/CARB	California Air Resources Board
API	American Petroleum Institute: degrees API is a widely used measure of gravity of crude oils
AP-42	Air Pollution 42 emissions factors
BACT	Best-Available Control Technology
BBL	One Barrel: a unit of volume equivalent to 42 US Gallons
B/D	Barrels per Day
BTU	British Thermal Units
BTX	Benzene, Toluene and Xylene (light aromatics)
C_3	Propane
C_4	Butane
Cet	Cetane index
CDU	Crude Distillation Unit
CEC	California Energy Commission
CEP	Car Efficiency Parameter
CO	Carbon Monoxide
CRU	Catalitic Reforming Unit
CS or cst	Centistokes: a measure of viscosity
EPA	United States Environmental Protection Agency
FCC or FCCU	Fluid Catalytic Cracking Unit
FOEB	Fuel Oil Equivalent Barrel (6.3 million BTU)

H_2	Hydrogen
HDA	Hydro-dearomatization unit
HCU	Hydrocracking unit
HDT	Hydrotreating unit
HGO	Heavy Atmospheric Gas Oil
HSFO	High Sulfur Fuel Oil
ISBL	Inside Battery Limits Process Unit Investment
LCO	Light Cycle Oil: middle distillate produced in the catalytic cracking process
LGO	Light Atmospheric Gas Oil
LP	Linear Programming
LPG	Liquefied Petroleum Gas
LSFO	Low Sulphur Fuel Oil
M	Thousand
MM	Million
MON	Motor Octane Number: a measure of the high speed performance of gasoline in the internal combustion engine
MTBE	Methyl Tertiary Butyl Ether: a high octane motor gasoline component
MOGD	Mobil Methanol to Gasoline and Diesel
MTG	Mobil Methanol to Gasoline process
MTO	Mobil Methanol to Olefins process
MVEG	Motor Vehicles Emission Group
NOX	Nitrogen Oxides
NPAH	Nitrated Polycyclic Aromatic Hydrocarbons
NPC	National Petroleum Council
NPRA	National Petroleum Refiners Association
PAH	Polycyclic Aromatic Hydrocarbons
PPM	Parts Per Million

PSI	Pounds per square inch
RFL	Refinery Fuel and Loss
RON	Research Octane Number: a measure of the low speed performance of gasoline in the internal combustion engine
(R+M)/2	Average of Research Octane plus Motor Octane
RVP	Reid Vapour Pressure: a measure of the volatility of gasoline
SCAQMD	South Coast Air Quality Management District
S	Sulfur
SOX	Sulfur Oxides
TBA	Tertiary Butyl Alcohol: a high octane motor gasoline component
TC	Thermal Cracking unit
TEL	Tetra Ethyl Lead: a gasoline additive for octane boosting
USGC	United States Gulf Coast
VBU	Visbreaking Unit
VDU	Vacuum Distillation Unit
VGO	Vacuum Gas Oil: a feedstock for cracking processes
VOC	Volatile Organic Compounds
VS	Viscosity