APPENDIX D

CRC VE-1 Committee Comments on ARB Staff Statistical Analysis

CRC STUDY AND DATA ANALYSIS

The Coordinating Research Council (CRC) is sponsoring a program to investigate the effects of diesel fuel properties on heavy-duty diesel exhaust emissions. This program is being conducted by the Southwest Research Institute (SwRI) and involves emission tests on a number of heavy-duty diesel engines using seven different diesel fuels. These fuels have different aromatic hydrocarbon content by FIA analysis, sulfur content, and volatility characteristics. The ARB participated in this program by sponsoring tests for two heavy-duty diesel engines using two additional fuels. Table 1 shows the average properties of the nine fuels used by SwRI in this program.

COMMENTS OF THE CRC-APRAC VE-1 PROJECT GROUP ON THE ANALYSIS OF THE VE-1 DATA BY THE AIR RESOURCES BOARD OF THE STATE OF CALIFORNIA

The purpose of the CRC VE-1 study was from its inception to determine the effect of diesel fuel properties on the exhaust emissions of several types of modern heavy-duty diesel engines. The interest of the Air Resources Board in the VE-1 results is the same, with the additional expressed purpose of using the understanding of fuel effects on emissions to propose regulations on diesel fuel properties. The VE-1 Project Group reviewed the Air Resources Board analysis of currently available results from the study and has concluded that the analysis of the data is too rudimentary to satisfy the objectives of the CRC study and the stated objectives of the Air Resources Board to control diesel emissions by regulation of fuel properties. This is exemplified by what follows.

Fuel sulfur has been excluded as a variable affecting tail pipe particulates in the Cummins engine by the ARB analysis on the basis of not meeting a 95% confidence criterion in the regression analysis. This conclusion is most probably incorrect, since sulfur is shown to be significant at better than 90% confidence in the ARB analysis and better than 95% in analyses using for example, the mass spectrographic data for one-ring and two-ring aromatics, in addition to fuel sulfur. Furthermore, direct measurement of sulfates on the particulate filters shows that nearly 2% of the fuel sulfur is converted to the sulfate form, and with associated water, appears as particulate from the engine.

The presumption, implied by the ARB analysis, that nitrogen oxide emissions are only, or primarily, affected by diesel fuel FIA aromatics are similarly subject to serious question. For example, fuel Cetane Number correlates as well, and better with nitrogen oxide emissions than do FIA aromatics. The effects of these and possibly other fuel parameters and their interactions, need to be identified by more rigorous analysis techniques such as analysis of errors, test of model fitness, co-variance analysis, etc.

Finally, we recommend that all regulated emissions, weighted suitably for the cold and the hot start EPA transient procedure, be also analyzed to determine their fuel property impact.

We believe that the data from this project, which has been generated with continual monitoring by the Project Group, is very suitable for assessing the impact of fuel properties on heavy-duty diesel emissions, all the more so, when data from the third engine is available. Valid conclusions on fuel effects, however, require a rigorous analysis of all the available data. It is the plan of the VE-1 Project to carry out such an analysis for inclusion in a final report on the three test engines to be available in the first quarter of 1989.

Table 1

Average Values of Properties of CRC Fuels

Fuel Number	FIA Aromatic Hydrocarbon Content (Vol. %)	Sulfur Content (Mass %)	90% BP °F
1	17	0.302	549
2	44	0.297	558
3	47	0.299	632
4	19	0.291	636
5	34	0.286	602
6	34	0.051	602
7	34	0.164	602
8	11	0.040	602
9	43	0.057	605

Source: Coordinating Research Council

Emission Tests for this program include the EPA standard transient test procedure and three steady-state operating modes. The emissions that are being evaluated include total particulate matter (PM), total hydrocarbon (HC), oxides of nitrogen (NO_x), carbon monoxide (CO), soluble organic fractions, sulfates, and benzene. So far, two heavy-duty diesel engines have been tested. The engine descriptions are presented below:

Cummins NTCC 400: A six-cylinder engine, 14 liter displacement, in-line, direct-injection, turbocharged, intercooled, rated power 400 hp at 2100 rpm, and fuel consumption 153 lb/hr.

Detroit Diesel DDC 60-11-315:

A six-cylinder engine, 11 liter displacement, in- line, direct-injection, turbocharged, intercooled, rated power 315 hp at 1800 rpm, and fuel consumption of 105 lb/hr.

The Cummins-400 engine was selected as an engine meeting the 1988 California emissions standards. The DDC-60 engine was selected and modified to approach the 1991 Federal emission standards. In addition to the two engines tested, Southwest Research Institute is currently testing a third heavy-duty diesel engine. The results from this engine are expected to be available by the end of 1988.

The two transient tests conducted are the hot-start andcold-start conditions. The three steady-state conditions are conducted with intermediate speed and 25 percent load (S1), rated speed with 25 percent load (S2), and rated speed with 75 percent load (S3).

The CRC steering committee for this project (VE-1 committee) agreed to release to the ARB, prior to completion of the study, the emissions test results for the two engines tested to date, with the understanding that the ARB staff would perform its own analyses and accept responsibility for the results and the conclusions reached. Analysis of data from the program is being conducted by Southwest Research Institute and will be made available in a report to be published in the first quarter of 1989.

The ARB staff analyzed the two engine test results separately for each engine tested and separately for each engine operating mode. We used the Statistical Analysis System (SAS) regression procedure (REG) computer programs. The REG procedure fits least-squares estimates to linear regression models and was used to perform analysis of variance for single and multiple regressions of aromatic hydrocarbon content, sulfur content, and 90 percent boiling temperature against total particulate matter, hydrocarbons, and NO_x emissions. Statistical F-tests were performed to evaluate how well the model accounts for the dependent variable(s) behavior and Student's t-statistics were used to determine if each independent variable contributes significantly to the regression model. Results of our analyses of the CRC data are included in Appendix __.

Table 2

Regression Equations for Diesel Fuel Properties
Diesel Engine Emissions

Engine	Regressions of Diesel Fuel Properties and Emissions
Cummins	PMCS (g/hp-hr) = 0.436563 + 5.375 x 10^{-3} x (% Aromatics)
	PMHS (g/hp-hr) = 0.370001 + 3.947 x 10^{-3} x (% Aromatics)
	NO_x CS (g/hp-hr) = 3.91181 + 11.89 x 10^{-3} x (% Aromatics)
	NO_x HS (g/hp-hr) = 4.28257 + 12.7932 x 10^{-3} x (% Aromatics)
DDC	PMCS (g/hp-hr) = 0.213869 + 215.976 x 10^{-5} x (% Aromatics)
	+ 0.149318 x (% S)
	PMHS (g/hp-hr) = 0.178086 + 97.1673 x 10^{-5} x (% Aromatics)
	+ 0.3211 x (% S)
	NO_x CS (g/hp-hr) = 3.9879 + 30.5947 x 10^{-3} x (% Aromatics)
	NO_x CS (g/hp-hr) = 9.3563 + 28.5266 x 10^{-3} x (% Aromatics)
	- 88.5758 x 10^{-4} x (90% Boiling Temperature)
	NO_x HS (g/hp-hr) = 3.84959 + 27.88859 x 10^{-3} x (% Aromatics)
	NO_x HS (g/hp-hr) = 6.45922 + 26.8833 x 10^{-3} x (% Aromatics)
	- 43.0576 x 10^{-4} x (90 % Boiling Temperature)

PMCS: Particulate Matter Cold-Start
PMHS: Particulate Matter Hot-Start
NO_xCS: NO_x Cold-Start
NO_xHS: NO_x Hot-Start
g/hp-hr: gram per brake horsepower-hour

APPENDIX E

ARB Staff Cost Estimate Methodology

A. METHODOLOGY FOR SMALL REFINERS

1. Estimation of Additional Process Capacity Required

The analysis was done for each small refinery using the following information from the ADL study:

- o Initial sulfur content of diesel fuel
- o Initial aromatics content of diesel fuel
- o Diesel fuel blendstock type information
- o Process unit information

a. Sulfur Content Reduction Regulatory Scenario

We estimated the additional process capacity required for the production of 0.05 percent sulfur by assuming that new hydrorefining (HR) capacity would be required for 55 percent of the refinery distillate process capacity. Based on the ADL information we assumed that HR would require about 600 standard cubic feet (scf) of hydrogen for every barrel of diesel fuel treated. We multiplied this by the HR capacity and estimated the hydrogen plant capacity needed for producing 0.05 percent sulfur diesel fuel.

b. Aromatics and Sulfur Content Regulatory Scenario

First, we estimated the additional hydrodearomatization (HDA) capacity required to meet the target aromatics value by the following equations:

$$[Aro.F].X + (D-X).[Aro.In.] = D.[Aro.\ T] \quad \text{where}$$

Aro. F = Aromatics level resulting by the HDA process; for this analysis is assumed 7 percent

X = HDA capacity required, barrels per day

D = Diesel production desired; for this analysis assumed 55 percent of the refiner's distillate production capacity

Aro. I = Initial aromatics level for this refinery

Aro. T = Target aromatics level; it is 20 percent, or 15 percent, or 10 percent, depending on the regulatory scenario.

By the use of the above equation, we estimated for each refinery the HDA process capacity required to meet the regulatory target in aromatics.

Second, to meet the 0.05 percent sulfur requirement, we assumed that all diesel fuel will be hydrorefined as in the sulfur content reduction scenario and therefore, this additional hydrorefining capacity is added. Because the hydrorefining satisfies the need for the first stage of the HDA process, only the second stage of the HDA process capacity estimated above was added.

Third, we estimated the hydrogen plant capacity needed by assuming that hydrorefining would require about 600 scf of hydrogen per barrel of diesel treated and that the second stage of the HDA process would require about 900 scf of hydrogen per barrel of diesel treated.

2. Estimation of Costs for the Additional Process Capacity

We estimated the capital costs of each new process capacity added for each small refinery by using the process capacity as estimated above and the process capital investment costs provided by ADL as shown in Table 1.

Table 1

Process Capital Investment Costs*

Process Unit	Capacity (MD/D)	Total Capital Investment (Million $)	Scale Exponent
Hydrorefining	10	23.2	0.70
Dearomatization (2nd Stage)	10	16.4	0.65
Hydrogen Plant (MMSCF/D)	50	48.2	0.70

* Include 50 percent for offsites.

The operating and other costs are linerly extrapolated from the data in the ADL study for each small refinery by using its diesel production capacity as estimated.

3. Cost-Effectiveness Analysis

First, the capital investment costs for each refinery and for each regulatory scenario were annualized using a 0.25 capital recovery factor. Second, the operating and other costs were added to the capital costs to develop the total costs for each refinery. The sum of the small refineries' costs are divided by the estimated diesel fuel production for 1990 to give the cost in cents per gallon of diesel fuel produced for each regulatory scenario for the year 1990.

The cost-effectiveness for each pollutant is estimatd by the following formula:

$$C/E = \frac{C}{E} \quad \text{where}$$

C/E = Cost-Effectiveness in $/lb

C = Cost in $/day

E = Emissions Reduction in lbs/day

This formula is used as follows:

For PM

$$C = \frac{T.C}{2} \quad \text{and} \quad E = (T.PM) \times \frac{(S.R)}{(T.R)} \quad \text{where}$$

T.C = Total cost to this Refinery Group in $/day = (cents per gallon) x (diesel production in gallons per day)

T.PM = Total statewide PM reductions in lbs/day

S.R = Small Refineries Diesel Production in California

T.R = All Refineries Diesel Production in California

For NOx

$C = \frac{T.C}{2}$ and $E = (T.NOx) \times \frac{(S.R)}{(T.R)}$ where

TNOx = Total statewide NOx reductions in lbs/day

For PM and NOx

$C = T.C$ and $E = (T.PM + NOx) \times \frac{(S.R)}{(T.R)}$ where

TPM + NOx = Total of statewide PM + NOx emission reductions

For Total Pollutants

$C = T.C$ and $E = (T.P) \times \frac{(S.R)}{(T.R)}$ where

TP = Total Emissions Reduction of all Pollutants (PM + NOx + SO_2); For SO_2 Estimated as Sulfates and Added to the PM Reduction, SO_2 is not included.

B. METHODOLOGY FOR LARGE REFINERIES

1. Estimation of Additional Process Capacity Required

The analysis was done for each large refinery using the following information from the ADL study:

a. All the hydrotreating process capacity (HDA, HDT, HDR) which was estimated by ADL was scaled to the 55 percent level on a per refinery basis.

b. All Mobil-to-Olefin-to Distillate process was scaled to the 55 percent level and was replaced with additional HDA process capacity. Because the Mobil process produces diesel fuel with a 3 percent aromatics content and the additional HDA is assumed to produce diesel fuel with 7 percent aromatics, we added HDA capacity equal to 2.5 times the diesel producing capacity of the Mobil process in order to achieve the same aromatics level reduction. However, we did not decrease the HDA process capacity estimated by the ADL to balance this increase in HDA capacity. Thus, in our methodology we overestimate the HDA process capacity required.

We estimated the total new process capacity required by adding the hydroprocessing capacity estimated by ADL with the hydroprocessing capacity that we estimated for the substitution of the Mobil process. For all new capacity, based on information provided in the ADL study on hydrogen requirements and blending feedstocks, we estimated hydrogen plant capacity required for each refinery. We estimated that on the average the two stage

HDA process would require about 1,100 scf of hydrogen per barrel and 1,300 scf of hydrogen per barrel for refinery groups III and IV, and V and VI, respectively. These numbers were multiplied by the HDA capacity to estimate hydrogen plant capacity needed for each refinery.

2. Estimation of Costs for the Additional Process Capacity

We estimated the capital and operating costs for each refinery in the large refinery category following the same approach as with small refineries using data on Table 1.

3. Cost-Effectiveness Analysis

Again, we used the same methodology and formula as in the case of small refineries with the difference of replacing the (SR) - Small Refinery diesel production factor with the (LR) - Large Refinery diesel production factor.

C. SENSITIVITY OF ADDING NEW HYDROREFINING CAPACITY

For each refinery for which hydrorefining (HR) capacity was not included in the ADL study, we added HR process capacity equal to the HDA capacity estimated by ADL. However, because all these refineries already operate a hydrotreater (HT) to produce low sulfur distillate we assumed that only the incremental capital investment and operating costs from hydrotreating to hydrorefining would apply. The incremental capital costs were estimated from Table 1, and the incremental operating costs were estimates from process information in the

ADL study. Again, we have assumed that only an incremental hydrogen capacity will be required to move from HT to HR. This was estimated from the ADL data on hydrogen requirements for these processes. For each refinery using the data from Table 1 and from the ADL process information, we estimated the capital and operating costs for the added HR and hydrogen plant capacity.

D. SEGREGATION COSTS

We assumed that the only segregation cost would be the cost of additional storage capacity to segregate the produced diesel fuel. For each refinery we estimated the storage capacity required by estimating the diesel production in barrels per day and multiplying it by 30 to provide 30 days of stroage capacity. We then used the following formula for cost:

$$\text{Cost (\$)} = 3.12\ (\text{Tank Volume}) + 47{,}590$$

To estimate the total cost, we increased the cost by 50 percent to include costs for associated equipment. This cost was totaled for small and large refineries and annualized by using a 0.25 capital recovery factor. The results were divided by the diesel production of each refinery group to estimate the cost in dollars per gallon of the tankage required for diesel segregation.

APPENDIX F

Submittals Made at the September 27, 1988, Consultation Meeting

CARB SEPTEMBER 27, 1988 DIESEL WORKSHOP

INTRODUCTION/BACKGROUND

- API/EMA PROPOSAL- DAVE SMITH ARCO/WOGA

ECONOMIC EVALUATIONS

- REFINERY - DOUG YOUNGBLOOD, TEXACO
- MARKET PLACE - TOM MANNING, PURVIN & GERTZ INC./WOGA CONSULTANT

EMISSION REDUCTIONS

- CRC DATA ANALYSIS - L. J. PAINTER, STATISTICAL CONSULTANT/CHEVRON
- IMPACTS ON DIESEL USERS - MIKE INGHAM, CHEVRON

COST EFFECTIVENESS - MIKE INGHAM, CHEVRON

ENFORCEMENT- DAVE SMITH, ARCO/WOGA

CARB SEPTEMBER 27, 1988 DIESEL WORKSHOP

API/EMA PROPOSAL

- EFFECTIVE OCTOBER 1, 1993 FOR ON-HIGHWAY DIESEL FUEL

  MAXIMUM - 0.05% SULFUR CONTENT
  MINIMUM - 40 CETANE INDEX

- CERTIFY 1991-93 ENGINES USING OCTOBER 1, 1993 DIESEL FUEL

- SPECIFICATIONS APPLY UNIFORMLY TO ALL

- NO ADDITIONAL SPECIFICATIONS NECESSARY

- NO REQUIREMENT TO PRODUCE OR MARKET ON-HIGHWAY DIESEL FUEL

- FOCUS OF ENFORCEMENT ON THE MISFUELER -- AUDITING DYEING, AND SPOT SURVEILLANCE

- SULFUR CONTENT AND CETANE INDEX CERTIFICATION BY IMPORTERS AND DOMESTIC SUPPLIERS OF ALL MIDDLE DISTILLATE FUEL

- BANKING AND TRADING IS NOT NECESSARY OR COST EFFECTIVE

***Comments based on August 3, 1988 letter from WOGA to Mr. Jim Boyd, CARB.**

CARB SEPTEMBER 27, 1988 DIESEL WORKSHOP

ENFORCEMENT*

- NO ACCEPTABLE ANALYTICAL METHOD FOR AROMATICS
- QUESTION OUR ABILITY TO OBTAIN PERMITS
- UNNECESSARY/DISRUPTIVE PRENOTICE REQUIREMENTS
  -ALTERNATIVES PROPOSED
- AVERAGING PERIOD TOO SHORT/MAINTENANCE EXEMPTION NEEDED
- VARIANCE PROVISIONS FLAWED

* Based on August 3, 1988 letter from WOGA to Mr. Jim Boyd, CARB.

ARB staff costs presented here are from the preliminary draft Technical Support Document. These costs have been modified in the final analysis.

ESTIMATE OF REFINING COST FOR PRODUCING

0.05% SULFUR, 20% AND 10% AROMATICS CONTENT DIESEL

BY

D. J. YOUNGBLOOD
TEXACO REFINING AND MARKETING INC.

SEPTEMBER 27, 1988

COST ESTIMATES FOR CONTROLLED DIESEL

CASE	ESTIMATE BASIS INDUSTRY SURVEYS INVESTMENT MM DOLLARS	INDUSTRY SURVEYS COST CENTS/GALLON**	A.D. LITTLE COST, CENTS/GAL	CARB ESTIMATE* COST CENTS/GALLON**
0.05% SULFUR	149.5	2.6	2.8	2.8
0.05% SULFUR/20% AROMATICS	716.1	10.6	N.A.	6.6***
0.05% SULFUR/10% AROMATICS	1331.7	19.5	23.3***	9.3***

*BASIS COMPOSITE OF LARGE AND SMALL REFINERIES FROM AUGUST 1988 CARB TECHNICAL SUPPORT DOCUMENT, TABLE 34. ASSUME SMALL REFINERIES DO NOT GO BELOW 20% AROMATICS AS CARB HAS PROPOSED.

**COST BASIS 152.5 MBPD CONTROLLED DIESEL.

***EXCLUDE IMPACT OF COST ESCALATION ABOVE INFLATION DUE TO HEAVY CONSTRUCTION DEMAND.

INDUSTRY INVESTMENT COST ANALYSIS

- COSTS BASIS 1986 NPRA (CALIFORNIA PORTION) AND 1984 CALIFORNIA REFINERY SURVEYS.

- SURVEYS ADJUSTED TO 152.5 MBPD DIESEL PRODUCTION TO PUT ON SAME BASIS AS CARB ESTIMATES.

- INVESTMENT COST ESCALATION DUE TO HEAVY LOAD ON CONSTRUCTION AND EQUIPMENT FABRICATION INDUSTRIES.

- CONSIDERED IMPACT THAT NEW TECHNOLOGY DEAROMATIZATION PROCESSING MIGHT HAVE ON INCREASING INVESTMENTS ABOVE INITIAL ESTIMATES. (BASIS RAND STUDY OF 12 REFINERY PROJECTS)

NPRA SURVEY FOR CALIFORNIA REFINERIES
FOR 20% AROMATICS/0.05% SULFUR DIESEL

REFINERY TYPE	TOTAL NO.	DIESEL B/D	DIST. NO. 2 B/D	COMMON DIESEL DIST. NO. 2 B/D	INVESTMENT MILLION $	OPER. COST $/DAY	TOTAL $/DAY	COST CENTS/ GAL*
SMALL	9	18,772	6,116	101	195	66,747	200,309	25.3
ALL LARGE	14	105,630	0	158,901	721	270,300	764,136	6.9
ALL CALIF.	23	124,402	5,116	158,901	916	337,047	964,445	8.1
ALL LARGE ADJ.**	14	152,500	135,919	0	504	188,985	534,259	8.3

*BASED ON DIESEL PLUS COMMON DIESEL/DIST. NO. 2 VOLUME AS CONTROLLED DIESEL.

**ADJUSTED TO 152.5 MBPD CONTROLLED DIESEL.

CALIFORNIA COST REQUIREMENTS - LARGE REFINERS ONLY

20% AROMATICS/0.05% SULFUR CASE	INVESTMENT MILLION $	TOTAL COST 000 $/DAY	TOTAL COST CENTS/GAL
BASE NPRA SURVEY ADJUSTED TO 152.5 MBPD DIESEL	504.1	534.3	8.3
(A) ADJUSTED FOR ESCALATION*	655.3	637.9	10.0
(B) ADJUSTED FOR (A) AND NEW TECHNOLOGY**	928.0	824.6	12.9
AVERAGE OF BASE AND ADJUSTED	716.1	679.5	10.6
10% AROMATICS/0.05% SULFUR CASE			
BASE 1984 SURVEY ADJUSTED TO 1987 COSTS	937.5	980.5	15.3
(A) ADJUSTED FOR ESCALATION	1218.8	1173.2	18.3
(B) ADJUSTED FOR (A) AND NEW TECHNOLOGY**	1725.9	1520.5	23.7
AVERAGE OF BASE AND ADJUSTED	1331.7	1250.5	19.5

*PROBABLE THAT INVESTMENT WILL ESCALATE AT LEAST 30% IN CONSTANT 1987 $ DUE TO HEAVY CONSTRUCTION DEMAND.

**BASIS RAND STUDY, LIKELY THAT SIGNIFICANT INVESTMENTS IN REFINING WILL BE 63% HIGHER THAN PROJECTED BEFORE PROJECT STARTED. THIS 63% HIGHER FACTOR APPLIED TO NEW TECHNOLOGY PORTION OF INVESTMENT WHICH BASIS 1986 NPRA DIESEL SURVEY WAS 66% OF TOTAL NEW INVESTMENT.

FACTORS THAT CONTRIBUTE TO ESCALATION COSTS ABOVE NORMAL

LIMITATIONS THAT WOULD IMPACT SCHEDULE AND INCREASE COST:

- ALLOY STEEL SUPPLY
- REACTOR SHOP AVAILABILITY
- COMPRESSOR SHOP AVAILABILITY
- EXCHANGER SHOP AVAILABILITY
- ENGINEERING MANPOWER
- CONSTRUCTION MANPOWER

ESTIMATE INVESTMENT COST WOULD ESCALATE 30% DUE TO HEAVY CONSTRUCTION DEMAND BASIS PAST EXPERIENCE.

RAND STUDY

- EXAMINED 52 COMPLETED CIVILIAN PROJECTS CONSTRUCTED INCLUDING 12 REFINERY PROJECTS.
- ALL PROJECTS EXAMINED ON 1984 PRICE BASIS WITH EFFECTS OF INFLATION REMOVED
- STARTING POINT FOR ORIGINAL COST ESTIMATE WAS ONSET OF DETAILED ENGINEERING (I.E., AT A POINT OF BETTER PROJECT SCOPE DEFINITION THAN INDUSTRY SURVEYS, A. D. LITTLE OR CARB ESTIMATES)
- KEY FINDINGS:
  - AVERAGE REFINERY PROJECT COST 63% MORE THAN ORIGINAL COST ESTIMATE
  - NO CORRELATION BETWEEN SIZE OR LOCATION OF PROJECT AND COST GROWTH
  - BIGGEST SINGLE FACTOR AFFECTING GROWTH WAS REGULATORY CONSTRAINTS ENCOUNTERED. REFINERY PROJECTS WOULD AVERAGE 44% MORE THAN ORIGINAL COST WITH REGULATORY CONSTRAINTS REMOVED.
  - LEVEL OF TECHNOLOGY INNOVATION IMPACTED COST WITH NEW TECHNOLOGY INCREASING COST.
  - PROJECT ESTIMATES BEFORE RESEARCH AND DEVELOPMENT WORK COMPLETED HAD MUCH GREATER COST GROWTH THAN THOSE MADE AFTER R&D COMPLETED.

COST ESTIMATES FOR CONTROLLED DIESEL

CASE	ESTIMATE BASIS INDUSTRY SURVEY	
	INVESTMENT MM DOLLARS	INCREASED COST CENTS/GALLON*
0.05% SULFUR	149.5	2.6
0.05% SULFUR/20% AROMATICS	716.1	10.6
0.05% SULFUR/10% AROMATICS	1331.7	19.5

*COST BASIS 152.5 MBPD CONTROLLED DIESEL.

COMPARISON TO A. D. LITTLE STUDY
FOR LOW SULFUR/20% AROMATICS DIESEL

	INDUSTRY SURVEY	A. D. LITTLE
AROMATICS REDUCED TO:	20%	20%
SULFUR REDUCED TO:	0.05%	0.14%
COST, CENTS/GAL.:*	8.1	3.8

*BASED ON 291.7 MBPD DIESEL FOR A. D. LITTLE AND 283.3 MBPD DIESEL FOR NPRA SURVEY.

FACTORS CONTRIBUTING TO A. D. LITTLE'S LOW COST ESTIMATES FOR AROMATICS REDUCTION

- UNREALISTIC LOW INVESTMENT FOR DEAROMATIZATION FACILITIES, RELYING ON EXISTING HYDROTREATING FOR FIRST STAGE OPERATIONS.

- FAILURE TO INCLUDE NEW HYDROGEN GENERATION FACILITIES.

- NOT INSTALLING FACILITIES TO REDUCE THE DIESEL SULFUR TO 0.05%.

A. D. LITTLE 20% AROMATICS CASE
BASE CASE AND ADJUSTMENTS

	DIESEL PROD. 000 B/D	PROCESS ADDITIONS: 000 B/D						REFINERY COST		
		NAPHTHA HDT	DIST. HDT	DIST. HDR	AROM. HDA	H2 PLANT	MOBIL PROCESS	COST 000 $/D	TOTAL INVEST MM $	TOTAL COST CPG
BASE*	291.7	3.5	0.0	51.5	105.7	0.0	1.9	466.7	410.1	3.8
BASE ADJ.**	291.7	3.5	17.0	39.3	105.7	123.8	1.9	963.5	974.4	7.9
BASE ADJ.**	152.5	1.8	8.5	20.7	55.4	64.8	1.0	564.1	625.5	8.8

*SULFUR .14 WT.%/AROMATICS 20 VOL.%

**SULFUR .05 WT.% AROMATICS 20 VOL.%. TWO ADJUSTED CASES SHOWN, ONE FOR 291.7 MBPD AND THE SECOND FOR 152.5 MBPD CONTROLLED DIESEL.

COMPARISON OF A. D. LITTLE STUDY FOR LOW SULFUR/20% AROMATICS DIESEL

	INDUSTRY SURVEY	A. D. LITTLE	A. D. LITTLE ADJ.
AROMATICS REDUCED TO:	20%	20%	20%
SULFUR REDUCED TO:	0.05%	0.14%	0.05%
COST, CENTS/GAL.:*	8.1	3.8	7.9
ADJUSTED COST, CENTS/GAL.:**	8.3	-	8.8
ADJ. COST WITH ESCALATION CENTS/GAL.:**	10.6	-	10.2

*BASED ON 291.7 MBPD DIESEL FOR A. D. LITTLE AND 283.3 MBPD DIESEL FOR NPRA SURVEY.

**BASED ON 152.5 MBPD DIEEL.

CARB ADJUSTMENTS TO 0.05% SULFUR/10% AROMATICS OF A. D. LITTLE ESTIMATE

	A. D. LITTLE	CARB ADJUSTED	% REDUCTION BY CARB	MAIN REASON FOR REDUCTION
DIESEL PRODUCED, MBPD	152.5	152.5	-	
CAPITAL INVESTMENT, MILLIONS $	781.87	523.79	33	ASSUMED COULD REMOVE MOBIL METHANOL TO DISTILLATE PROCESSES AND REPLACE WITH HYDRO DEARMOTIZATION AT AN ASSUMED RATIO.
COSTS, THOUSANDS DOLLARS/DAY				
CAPITAL COSTS	542.37	358.75	34	
OPERATING COSTS	950.36	237.46	75	ELIMINATED ALL FEEDSTOCK COSTS AND ASSUMED OTHER OPERATING COSTS WOULD NOT CHANGE.
TOTAL COST	1492.73	596.21	60	
TOTAL COST, CENTS/GAL	23.3	9.3	60	DECRESED DUE TO A SIGNIFI CANT NUMBER OF ARBITRARY ADJUSTMENTS*

*WHEN A. D. LITTLE REPLACED MOBIL PROCESSING WITH HYDRODEAROMATIZATION IN 15% AROMATICS CASE (BY INCREASING METHANOL PRICE FROM 30 TO 70 CENTS/GAL) COST INCREASED ABOUT 90%.

SUMMARY

- CARB COSTS FOR PRODUCING LOW AROMATICS DIESEL UNDERSTATED DUE TO ARBITRARY ADJUSTMENTS MADE TO A. D. LITTLE STUDY AND FAILURE TO RECOGNIZE IMPACT OF ABOVE NORMAL INVESTMENT COST ESCALATION DUE TO HEAVY DEMAND ON CONSTRUCTION INDUSTRY.

- BEST SOURCES AVAILABLE FOR ESTIMATING COSTS ARE 1986 NPRA SURVEY AND 1984 CALIFORNIA SURVEY ALTHOUGH 1984 CALIFORNIA SURVEY PROBABLY UNDERESTIMATES COSTS.

- OUR ESTIMATED COST TO PRODUCE 0.05% SULFUR AND 20% AROMATICS DIESEL FOUR TIMES GREATER THAN THAT FOR PRODUCING 0.05% SULFUR DIESEL INCREASING TO 7.5 TIMES GREATER FOR PRODUCING 10% AROMATICS DIESEL.

- RECOMMEND THAT CALIFORNIA FOLLOW RECOMMENDATION PROPOSED JOINTLY BY ENGINE MANUFACTURERS AND PETROLEUM REFINERS TO REQUIRE CONTROLLED DIESEL TO MEET 0.05% SULFUR AND 40.0 MINIMUM CETANE INDEX REQUIREMENTS.

PRELIMINARY DRAFT

WESTERN OIL AND GAS ASSOCIATION

POTENTIAL IMPACTS OF LOW AROMATICS DIESEL FUEL REGULATIONS

September 1988

Thomas J. Manning
John H. Vautrain

TABLE OF CONTENTS

		PAGE
I	INTRODUCTION	1
II	SUMMARY AND CONCLUSIONS	2
III	IMPACT OF PROPOSED LOW AROMATICS DIESEL RULE	3
	CALIFORNIA DISTILLATE DEMAND	3
	NEVADA DISTILLATE DEMAND	4
	ARIZONA DISTILLATE DEMAND	4
	CONTROLLED DIESEL PRODUCTION	5
	SOURCES OF LOW AROMATICS DIESEL	6
	PRICING THEORY	9

I

INTRODUCTION

Western Oil & Gas Association (WOGA) retained Purvin & Gertz to develop a report addressing three aspects of the proposed California Air Resources Board (ARB) regulation governing the aromatics content of diesel fuels for motor vehicles. The purpose of this report is for presentation to the ARB to inform them of the ramifications of the proposed regulation. The three topics which will be covered in this report are: 1) supply and demand of diesel fuel in California, 2) possible sources of low aromatics diesel fuel or diesel fuel blendstocks located outside California, and 3) possible diesel fuel price impacts of the proposed rule. The impact of these possible price effects on various consumer groups will be illustrated as well.

Supply and demand figures are derived from publications of the California Energy Commission (CEC) and the U.S. Department of Energy (DOE). In evaluating external sources of blendstocks, Purvin & Gertz data regarding the quality of crude oils from around the world and information from process licensors was used. Pricing impacts have been evaluated based on basic economic theories and data reported by A.D. Little (ADL) in their report to the ARB. The ADL data has not been independently evaluated and its use does not constitute endorsement of its findings. Rather it is used to illustrate to the ARB how refining cost effects may be translated into pricing implications for diesel.

II

SUMMARY AND CONCLUSIONS

Our major findings are as follows:

- Distillate/diesel demand in California has been increasing at an average annual rate of about 5% since 1976. California refineries produce a surplus of distillate which they export or transfer to other states. California refiners seek to minimize distillate production by using their hydrocrackers to maximize gasoline and jet fuel.

- The aromatics content of California distillate averages about 30% because of the qualities of the California crudes and Alaskan North Slope crude run and refinery configuration.

- We were unable to identify any significant volumes of low aromatics blendstocks to be used by California refineries to produce low aromatics diesel.

- Based on the ADL report prepared for the ARB, it appears that the cost of producing low aromatics diesel by the Groups V and VI refineries will determine the level of pricing for controlled diesel since they represent the most expensive increment of supply required to satisfy demand.

- The cost data and assumptions in the ADL report, combined with the 1986 level of demand for controlled diesel, indicate that the imposition of a low aromatics diesel specification would likely cause the price of diesel fuel in California to increase significantly. The impact to consumers would be in the range of at least $400-600 million annually.

III

IMPACT OF PROPOSED LOW AROMATICS DIESEL RULE

In order to assess the impact of the proposed low aromatics diesel rule, the supply, demand and pricing for that portion of the distillate pool which would be impacted must be determined. For purposes here, three data sources were utilized for this determination.

1. California Energy Commission (CEC) Quarterly Reports
2. U.S. Department of Energy (DOE)
3. Arthur D. Little report prepared for the California Air Resource Board (8/5/88)

CALIFORNIA DISTILLATE DEMAND

The supply/demand balance for California distillate is shown in Figure III-1. The data was obtained from the quarterly reports issued by the California Energy Commission. California refiners produce more distillate than is consumed in the state and the surplus is exported or shipped to other states. The amount varies from year to year, but the surplus has been in the range of 30,000 to 50,000 B/D during the 1976-87 time period.

As shown in Figure III-1, consumption of distillate has exhibited an annual growth rate of about 5% from 1976-87. Distillate includes diesel fuels, and No.1 and No. 2 fuel oils used for heating.

The consumption pattern for California distillate for 1986 (the latest year for which data is available) is illustrated in Figure III-2. On-highway use of distillate accounts for about 50% of the total, all of which is diesel fuel. As shown on Figure III-2, the balance of consumption is divided fairly evenly between the other sectors. There is a small amount of non-engine use of distillates in some of these sectors. In the agricultural sector, for instance, there is some use of distillate for heating purposes. However, the predominant use of distillates is for engine fuel. Figure III-3 shows the volume of diesel fuel in the various sectors. Data in Figure III-3 are derived from DOE consumption-by-sector information and specifically exclude heating fuel uses.

It could be that some of the diesel consumption indicated in Figure III-3 may not fall under the "controlled diesel" definition, but the over-statement is not large. For example, all of the on-highway use

is certainly controlled diesel, as well as most of the military use. In the farm sector, most of the diesel is for moving vehicles, but some diesel may be used for diesel-driven irrigation pumps. Some of the use in the other sectors may be for stationary engines, but we believe such usage to be relatively small. Based on the DOE and CEC data, a total of 210,000 barrels per day of diesel fuel was used in 1986 in uses which would be entirely or predominantly controlled under the proposed regulation.

There is a reasonable amount of waterborne traffic in distillates between California and neighboring states, as well as exports. The net trade balance for the two major producing regions (Los Angeles and San Francisco) is illustrated in Figure III-4.

Traffic varies considerably from port to port and is different each year, but the flows shown in Figure III-4 are representative of recent years. Typically, California shows a positive trade balance with other states of around 10,000 B/D and net exports are usually about 20,000 to 30,000 B/D annually.

California has an extensive network of product pipelines most of which are illustrated in Figure III-5. In addition to serving the California market, the product pipelines allow California marketers to ship products to Nevada and Arizona. The lines move gasoline, distillate and jet fuel. Distillate movements out-of-state average about 15,000 B/D to Nevada and 15,000 to 20,000 B/D to Arizona.

NEVADA DISTILLATE DEMAND

Consumption of distillate in Nevada has been about 15,000 B/D annually for the last several years (Figure III-6). Demand is split about 60% diesel fuel and 40% distillate for heating. Essentially all of Nevada's supply comes from California. The Reno market is served by the Southern Pacific pipeline with product from San Francisco. Southern Nevada, represented by Las Vegas, is served by the Calnev product line with product from the Los Angeles area refineries.

ARIZONA DISTILLATE DEMAND

Demand for distillates in Arizona is about double that of Nevada, and in 1986 consumption was about 30,000 B/D (Figure III-7). Approximately 70% of the demand is diesel with the balance used for heating purposes. It is estimated that approximately half of Arizona's

demand is supplied by California refineries with the balance supplied from West Texas refineries.

CONTROLLED DIESEL PRODUCTION

The proposed regulations controlling the sulfur and aromatics content of diesel fuel in California are intended to control the diesel fuel used in all "motor vehicles". A motor vehicle is defined as "a vehicle which is self-propelled". We understand that the intention of the California Air Resources Board is to control all fuel in motor vehicles which can potentially utilize California roadways. This would include diesel fuel with the following end-use:

Controlled Diesel Fuel
- On-road Motor Vehicles
  - Automobiles
  - Trucks
  - Buses
- Construction Vehicles
- Agricultural Vehicles
- Military Vehicles

This leaves the following diesel fuel categories non-controlled:

Non-Controlled Diesel Fuel
- Industrial
- Marine
- Railroad

As detailed earlier, the total consumption of diesel fuel in sectors which would be controlled was about 210,000 B/D in 1986. Figure III-8 shows the breakdown of distillates produced in California into four sectors. Controlled diesel is the largest segment at 210,000 barrels per day. Exports to foreign nations or to neighboring states, about 44,000 barrels per day, would be of uncontrolled material regardless of end-use. Uses of diesel in marine, railroad, and industrial applications, about 37,000 barrels per day, would not be controlled. Finally, about 13,000 barrels per day of distillate fuel oils, that is materials used for heating applications would not be controlled.

SOURCES OF LOW AROMATICS DIESEL

Like many petroleum products diesel fuel is blended in refineries from blendstocks originating in various process units. Even if there is not a discernible source of low-aromatics finished diesel for sale, the possibility of purchasing low-aromatics blendstocks needs to be addressed. If such blendstocks could be found in substantial quantities, this could affect the price impacts of a low-aromatics regulation. Such a possibility is discussed in the ADL report. In order to evaluate the possibility of finding substantial quantities of low-aromatics diesel blendstocks in the world market, each type of material normally blended to diesel fuel was evaluated separately. Diesel fuel blendstocks are divided into the four categories below:

- Straight-Run Distillates
- VGO Hydrocrackates
- FCC Cycle Oils
- Coker Distillates

Straight-run distillates refer to those materials which are simply distilled from crude oil. These materials may be hydrotreated to remove sulfur but such processing has little impact on aromatics content. As will be discussed more fully below, VGO hydrocrackers are used in many world locations specifically to produce diesel or distillate fuels. FCC cycle oils are produced in fluidized-bed catalytic crackers. These units are common around the world and are used most commonly to produce gasoline. The cycle oils are diesel-type co-products of the process. Cokers are refinery process units which convert asphalt-like materials into lighter products boiling in the gasoline or diesel range. Coker distillates refer to the distillate-range materials produced in such units. Like straight-run distillates, cycle oils and coker distillates may be hydrotreated for stability and to remove sulfur though such processing is usually of mild severity and has little impact on aromatics content.

If any of these blendstocks with sufficiently low aromatics content could be located at any world location in significant quantities, it might be possible to import such blendstocks to produce low aromatics diesel in California.

We undertook a thorough analysis of the straight-run distillates from the major crude oils in the world and determined that it is highly

unlikely that significant supplies of low aromatics straight-run diesel could be found. Major crude oil or product exporting regions are discussed individually below:

Middle East : The Middle East is a major supplier of crude oils to the world's refineries. However, based on the crude assays we were able to assemble, we estimate the the typical straight-run distillates would have an aromatics content of 20-30% and a sulfur content of about 1%.

Indonesia/Far East : Indonesia is a major exporter of light sweet crudes, but the crudes yield a straight-run distillate with moderately high aromatics content. For example, Minas crude (one of the major export crudes) yields a straight-run distillate with an aromatics content of about 15%. This obviously could not be used to blend with higher aromatic diesels in California to meet a 10% aromatics specification. The problem is further complicated by the fact that the Far East crudes tend to be waxy. Waxy diesel fuels have unacceptably high pour-point. The waxes are paraffinic and when they are removed to make acceptable pour-point quality, the aromatics are concentrated in the remaining material and the percentage aromatics increases.

North Sea : Production of North Sea crudes total over 3 million B/D of light sweet crude. The aromatics content of straight-run distillate from most North Sea crudes is about 25%. Sulfur content is usually quite low, about 0.10%. We only found one small field (about 30,000 B/D) where the crude assay indicated a straight-run distillate with a low aromatics content. It is unclear logistically how this crude is transported and it may be unavailable prior to blending with other higher-aromatics crudes. The North Sea crude or products produced from it are logistically disadvantageous to serve the West Coast market.

U.S. Gulf Coast : Most of the U.S. Gulf Coast crudes yield a straight-run distillate with an aromatics content of 25-30%. The light sweet South Louisiana crudes yield straight-run distillate with about 20% aromatics. Some Louisiana condensates' assays indicate that they might yield a low aromatics straight-run material. However, total production is 200,000 B/D or less, and these condensates are produced at widely dispersed locations. It would be difficult, if not

impossible, to economically segregate significant volumes of low-aromatics condensates because they generally are blended in the field with other crudes and moved to market in a common pipeline.

PADD V/California : Onshore California crudes tend to be heavy, high sulfur crudes, and yield high aromatics straight-run diesel. California crudes are not plentiful enough to meet the needs of the California refineries, so Alaskan North Slope (ANS) crude makes up the shortfall. ANS is a relatively heavy (27°API) moderately high sulfur (1%) crude and it also yields a high aromatics straight-run distillate. This is reflected by the over 30% average aromatics content of California diesel fuels.

Two of the other distillate blendstocks -- catalytic cracker (FCC) cycle oils and coker distillates -- do not represent a source of low aromatics blendstocks. Aromaticity of these streams is a function of the crudes fed to the refineries and the severity of processing in the FCC's and cokers. In all cases, these blendstocks contain more aromatics than the straight-run distillate of their respective crudes. The high level of aromatics in these blendstocks is reflected by their low cetane numbers which limits the amount of these materials incorporated into finished diesel fuel.

In many areas of the world, hydrocrackers are used specifically to produce distillates and hydrocrackates comprise a significant portion of the distillate pool. However, such is not the case in California. In California the hydrocrackers were installed to minimize distillate and increase gasoline and jet fuel production due to the high rates of demand for these products relative to distillate. California is short of jet fuel, short to balanced on gasoline, and long on distillate as demonstrated earlier in this report.

Aromatics content of hydrocracked jet fuels are commonly measured because of the need to meet jet fuel aromatics specifications. Hence there is substantial commercial data regarding the aromatics content of hydrocracked jet fuel. Typical aromatics specifications are 20% for commercial jet fuel. Hydrocracked jet fuels usually are found to meet this specification but would not meet a 10% aromatics specification. Furthermore, hydrocrackers are not designed to have good control over aromatics content of their products. Because of side reactions occurring in the hydrocracker, aromatics content of the products usually rises as catalysts age.

Because there currently are no aromatics specifications for diesel fuel, commercial data regarding the aromatics content of hydrocracked distillates is sparse. Based on the observations regarding jet fuel co-produced with the hydrocracked distillates, it is quite unlikely that such materials would have aromatics content low enough to contribute to the solution of the problems posed by the proposed regulation.

PRICING THEORY

Economic theory indicates that there is a relationship between the price of any product and the demand for the product. As illustrated in Figure III-9, a decrease in the price of product will increase demand and vice versa. This is referred to as demand elasticity. The slope of the elasticity curve is determined by the nature of the product, the availability of suitable substitutes and other factors. At constant price, many products would experience a natural increase in demand over time as the population expands and economic activity increases. This would be reflected by a shift in the curve to the right and would be true of a product like diesel fuel. Government regulations can influence the demand curve. For instance, the Corporate Average Fleet Economy (CAFE) standards of the 1970's were a deliberate attempt by the federal government to decrease the demand for gasoline even without a price increase. The effects of such a policy would be to shift the demand curve to the left.

Supply of products is responsive to price changes as well. As prices increase, more suppliers will enter a marketplace increasing the amount of a product available to the public. This is illustrated by the Figure III-10. The supply curve also can be shifted by a variety of factors. Tariffs or quotas often are used by governments to reduce the supply of a commodity at a given price in order to achieve a policy objective. This would be reflected by a movement of the supply curve to the left. Production subsidies might be used by governments to increase the supply of a product at a given price and shift the supply curve to the right.

When the supply and demand curves are overlaid, there is an equilibrium point (Points P_1 and Q_1 in Figure III-11) where supply and demand balances with the price of the commodity. Prices in excess of this

equilibrium point would be unsustainable. Additional, more expensive increments of supply would enter the market while demand would shrink. This dis-equilibrium would tend to drive prices lower. Likewise prices under the equilibrium point are unsustainable. Demand would be greater than could be supplied at that price and prices would be driven upwards. Market prices may be thought of as being determined by the most expensive increment of supply necessary to meet market demand.

Regulations such as the proposed low aromatics diesel rule could displace the supply curve to the left by increasing costs for all producers and cause the availability of products to shrink without an increase in prices (P_1,Q_2) or cause the price to increase to maintain supply (P_2,Q_1). Point (P_3,Q_3) shows the new equilibrium point which would be established after the shifting of the supply curve.

The foregoing economic theory is applicable to the proposed low aromatics diesel regulation. ADL was commissioned by the ARB to estimate the cost of producing low aromatics diesel in California. The ADL data can be used to estimate the supply curve for low-aromatics diesel fuel. ADL used selected refiners to represent industry segments:

Group	Definition
I	Topping
II	Hydroskimming: Kern Oil, Bakersfield
III	Conversion: FCC or Hydrocracking - Unocal, LA
IV	Deep Conversion: Coking, no Hydrocracking - Shell, Wilmington
V	Deep Conversion: Coking with Hydrocracking, LA Basin - Arco, Carson
VI	Deep Conversion: Coking with Hydrocracking, Northern California - Exxon, Benicia

They then used refinery modeling procedures to approximate the cost of producing low aromatics diesel in each group. Purvin & Gertz does not necessarily accept ADL's approach or the characterization of the costs of low aromatics diesel production, but ADL's results are reported in Figure III-12 to illustrate the pricing theory discussed above.

ADL combined Group III and IV together for confidentiality and we grouped V and VI together because VI represents the production at San Francisco and these refineries would need to operate to meet demand in northern California.

It can be seen that based on an estimate of the demand for

controlled diesel and ADL's estimate of the additional cost of producing diesel with only 10% aromatics and 0.05% Sulfur that diesel production by the refineries in Groups III, IV, V, and VI would be required if the demand for controlled diesel fuel were to be met. The price of controlled diesel in California will reflect the cost of the last increment of supply required to satisfy demand. According to the ADL data, this would be refineries in Group VI. Since the cost of making low aromatics diesel in refineries in Groups I and II is so high, they will likely just continue to make non-controlled product. Figure III-12 shows a vertical line for demand at the 1986 level. This is not intended to suggest that demand for diesel fuel is completely inelastic but rather indicates only that this elasticity has not been estimated. Based on the ADL data and recent demand levels for diesel fuel in the controlled categories, price impacts in the 12.1-19.2 cents per gallon range would be expected. The price increase would be greater if adjusted according to ADL's sensitivity analysis to cover the availability of cheap methanol.

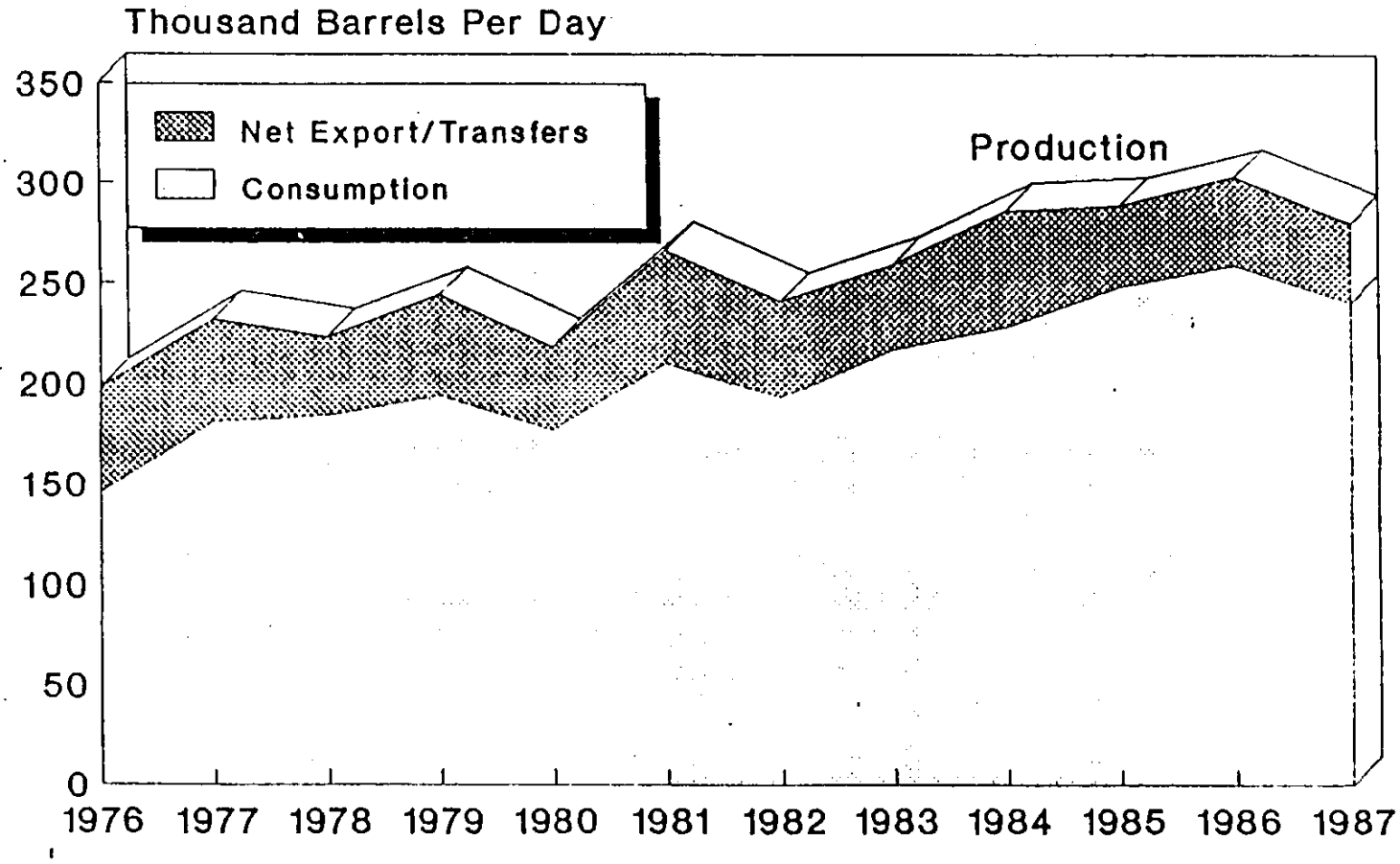
If the cost of diesel increases as much as suggested by the ADL data, the impact on the consumer would be significant. The impact shown in Figure III-13 was calculated based on the consumption of controlled diesel in the various sectors in 1986. These data were calculated by multiplying the price impact based on the ADL study by the volume of diesel fuel consumed by each sector in 1986. This may understate the total impact since consumption of controlled diesel is expected to grow based on the historical growth patterns. A range of impacts is shown for each consumer group correspondi ıg to the range of possible refining costs indicated by ADL.

On-highway users of diesel fuel as the largest element of consumption are impacted to the greatest degree. This group may see cost increases in the range of $240-380 million dollars per year. Agricultural users of diesel may be faced with cost increases of $31-49 million dollars per year. Total impacts are estimated to be $390-618 million per year.

FIGURE III-1

CALIFORNIA DISTILLATE

SUPPLY/DEMAND BALANCE



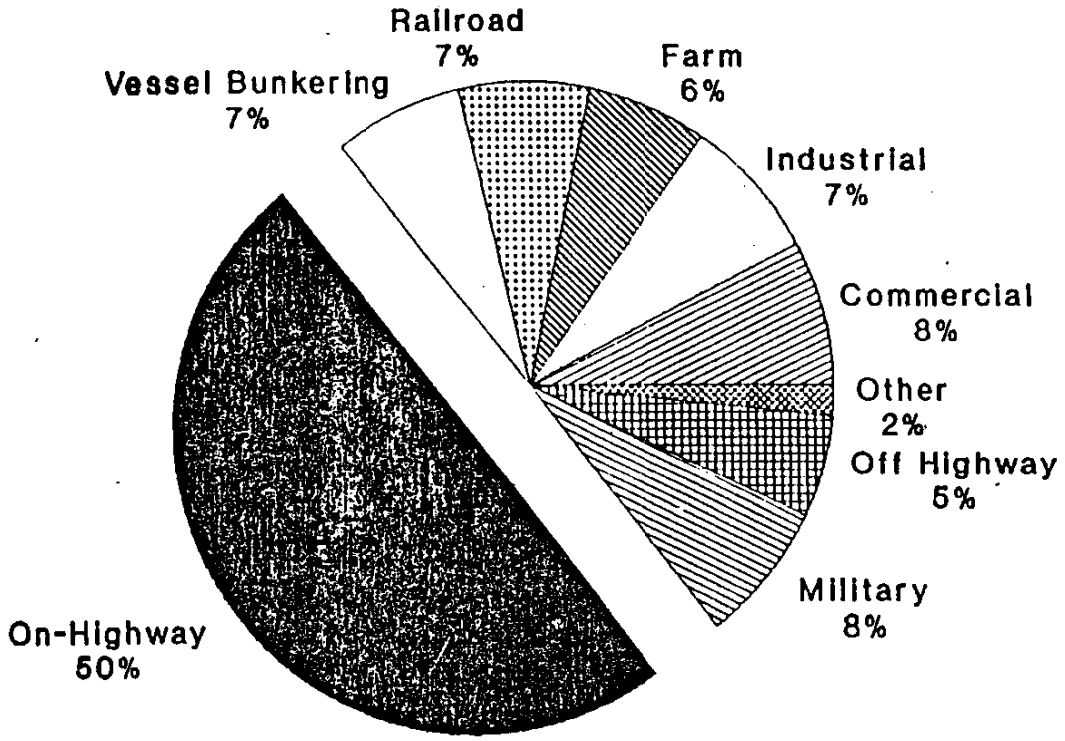
Source: California Energy Commission, Quarterly Reports

FIGURE III-2

CALIFORNIA DISTILLATE/DIESEL FUEL

CONSUMPTION BY SECTOR: 1986

Percent



Source: DOE, Petroluem Marketing Monthly

FIGURE III-3

CALIFORNIA DIESEL FUEL

CONSUMPTION BY SECTOR: 1986

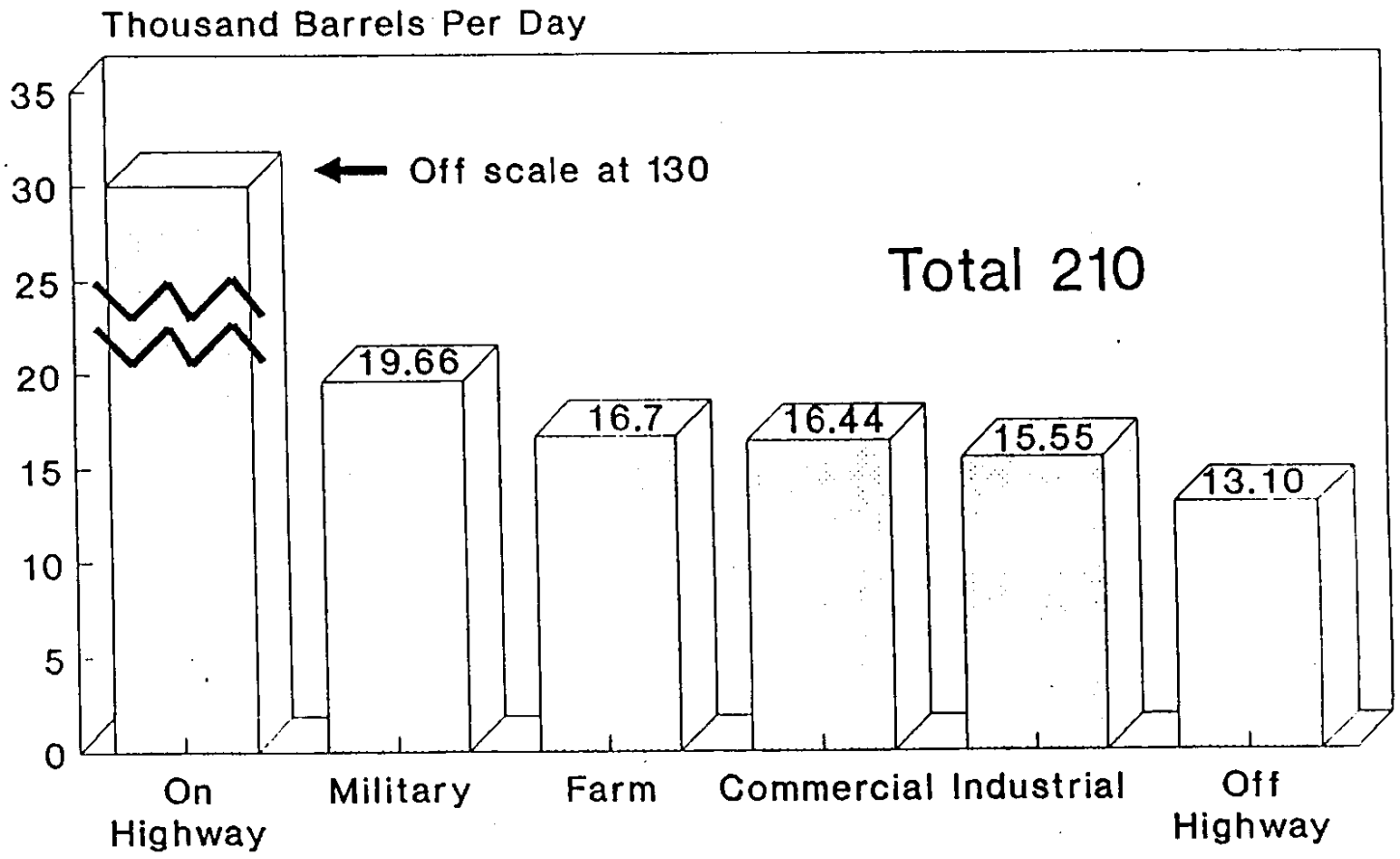


FIGURE III-4

WATERBORNE SHIPMENTS OF DISTILLATE

EXPORTS AND DOMESTIC SHIPMENTS (MB/D)

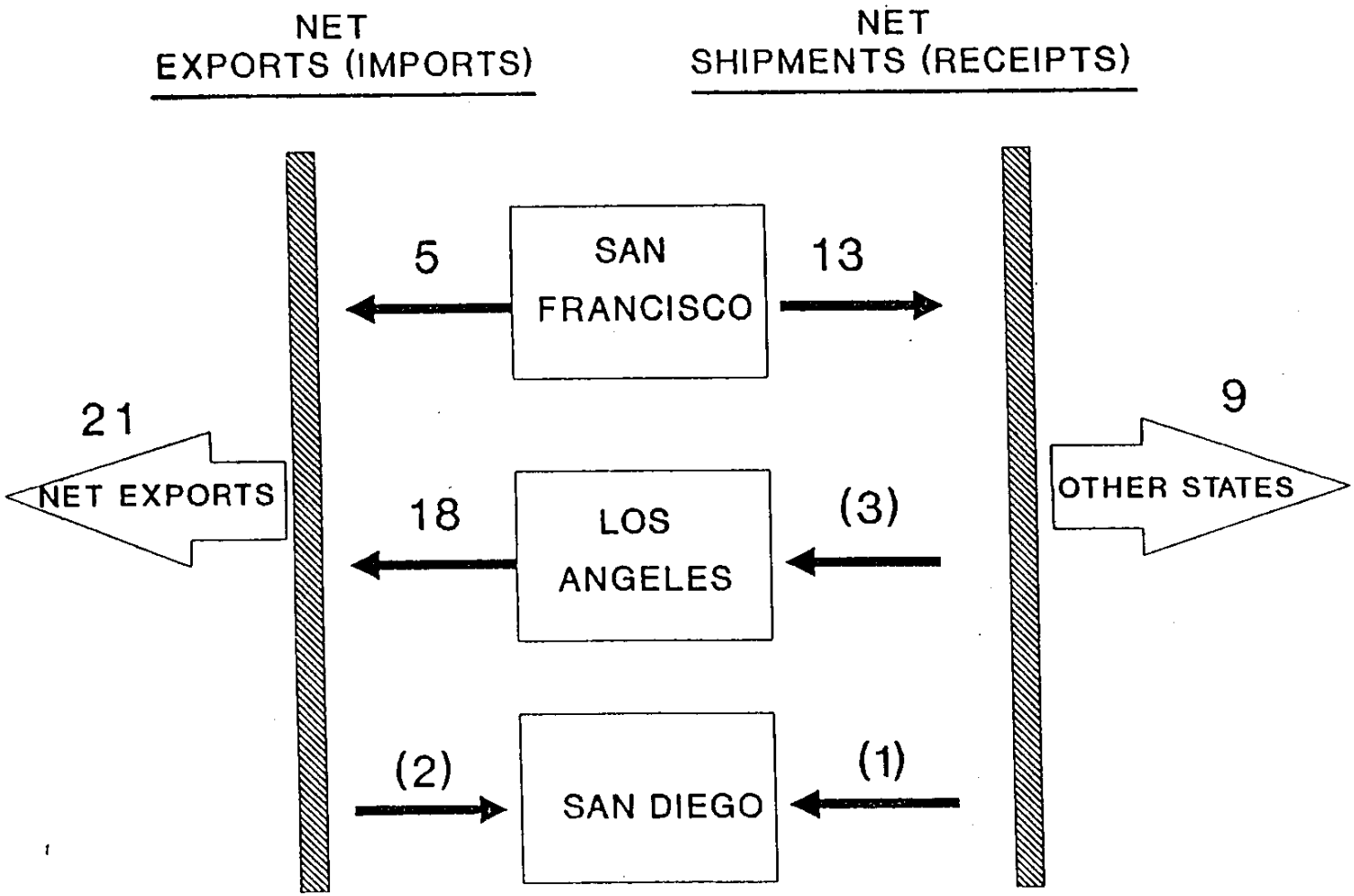


FIGURE III-5

MAJOR PRODUCT PIPELINE SYSTEMS

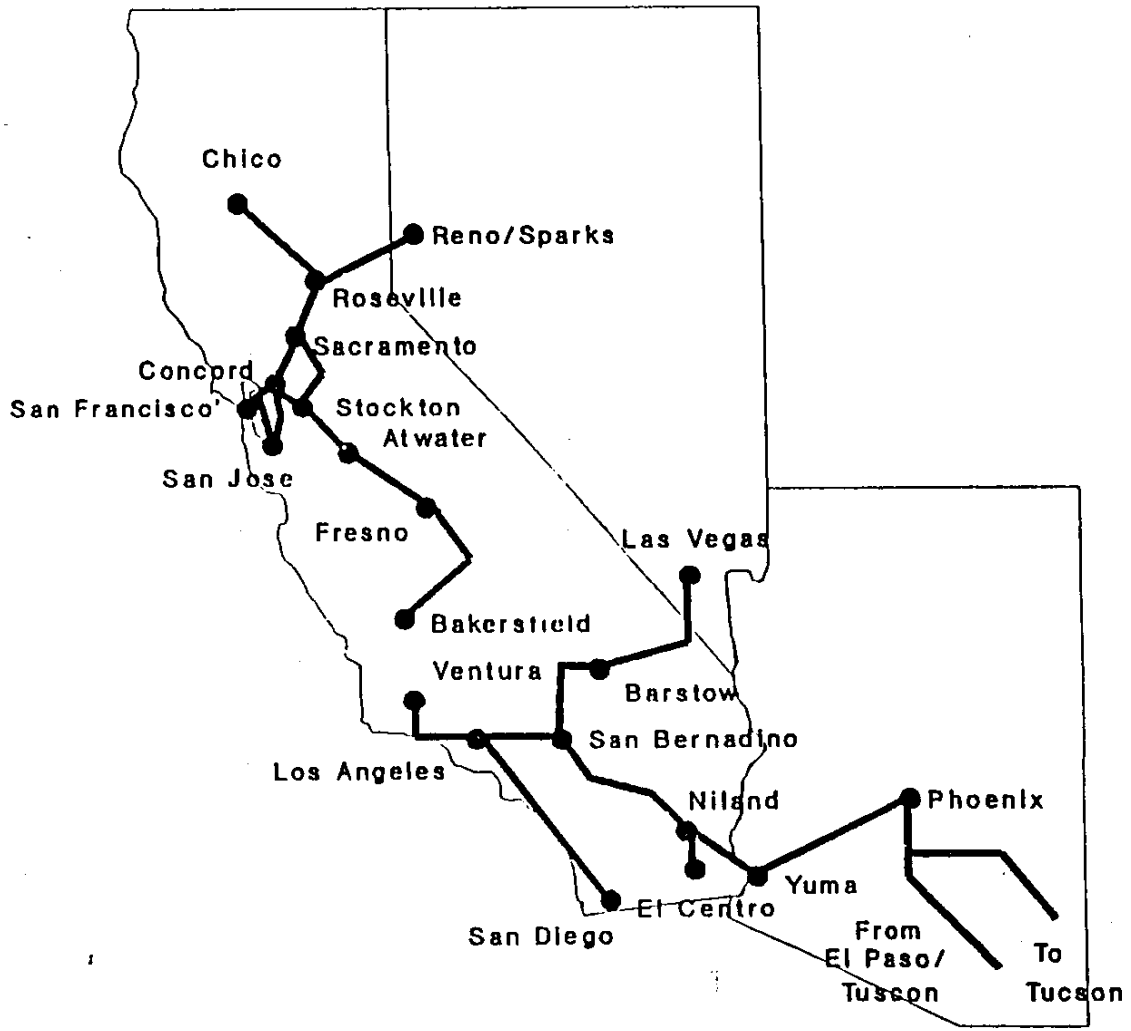
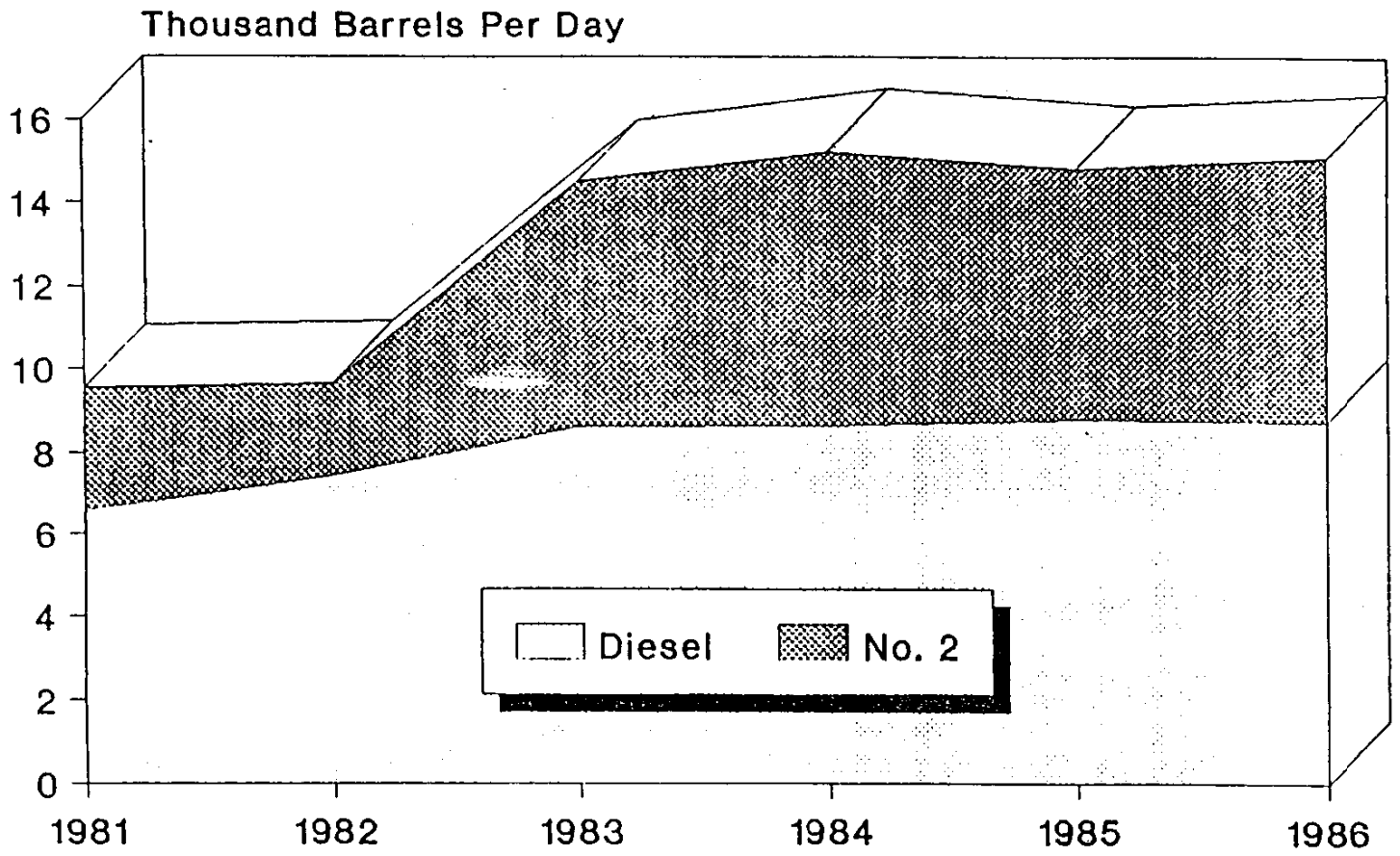


FIGURE III-6

NEVADA DISTILLATE CONSUMPTION

CONSUMPTION

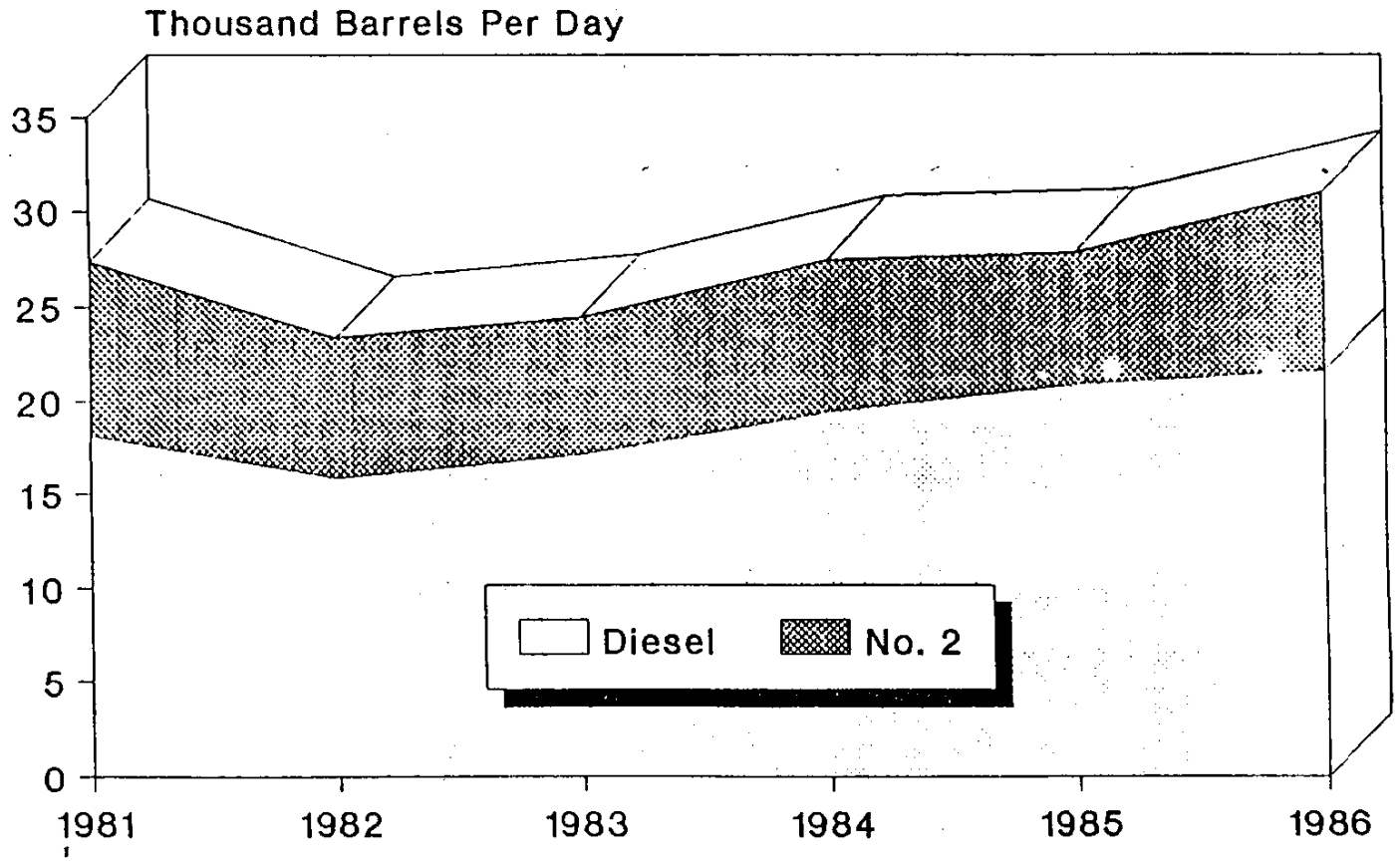


Source: DOE, Petroleum Marketing Monthly

FIGURE III-7

ARIZONA DISTILLATE CONSUMPTION

CONSUMPTION



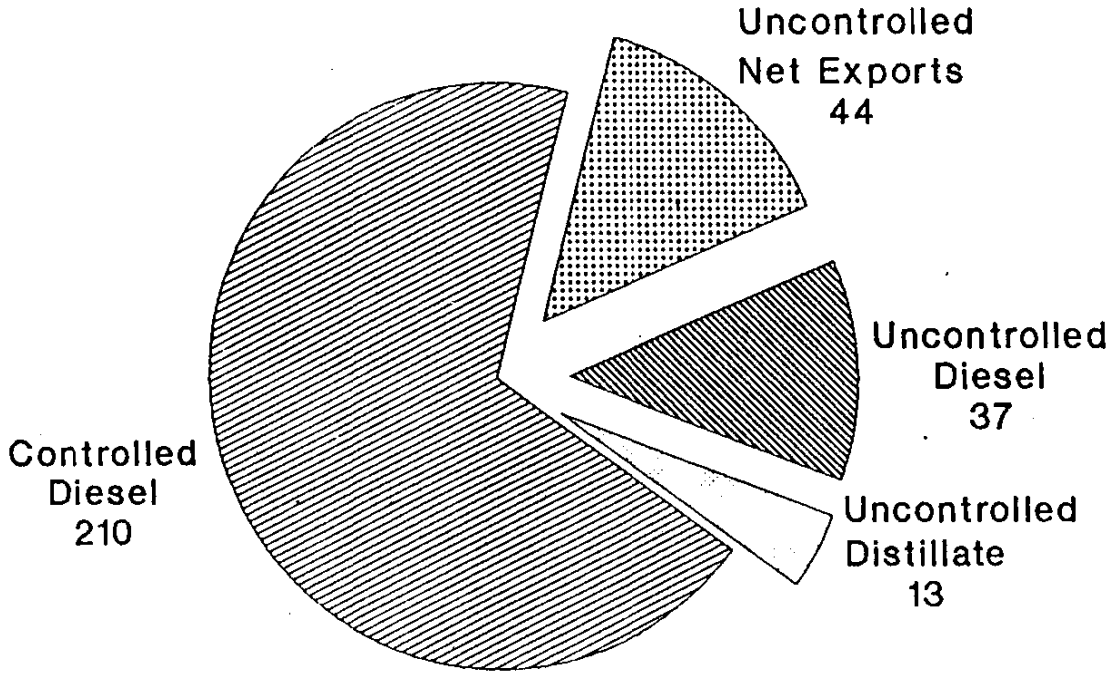
Source: DOE, Petroleum Marketing Monthly

FIGURE III-8

CALIFORNIA DISTILLATE/DIESEL

PRODUCTION: 1986

Thousand Barrels Per Day



304 MB/D

FIGURE III-9

DEMAND ELASTICITY

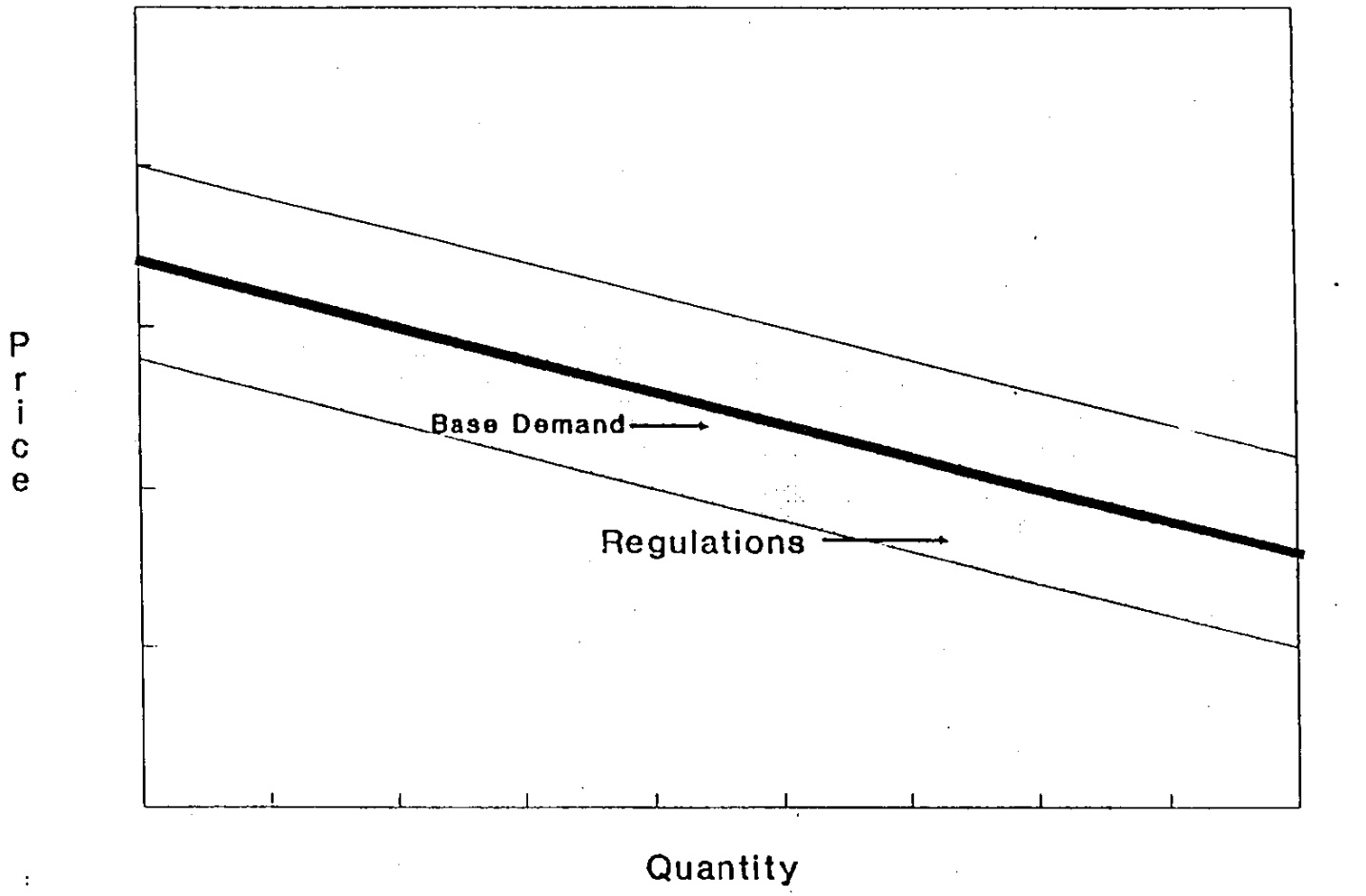


FIGURE III-10

SUPPLY ELASTICITY

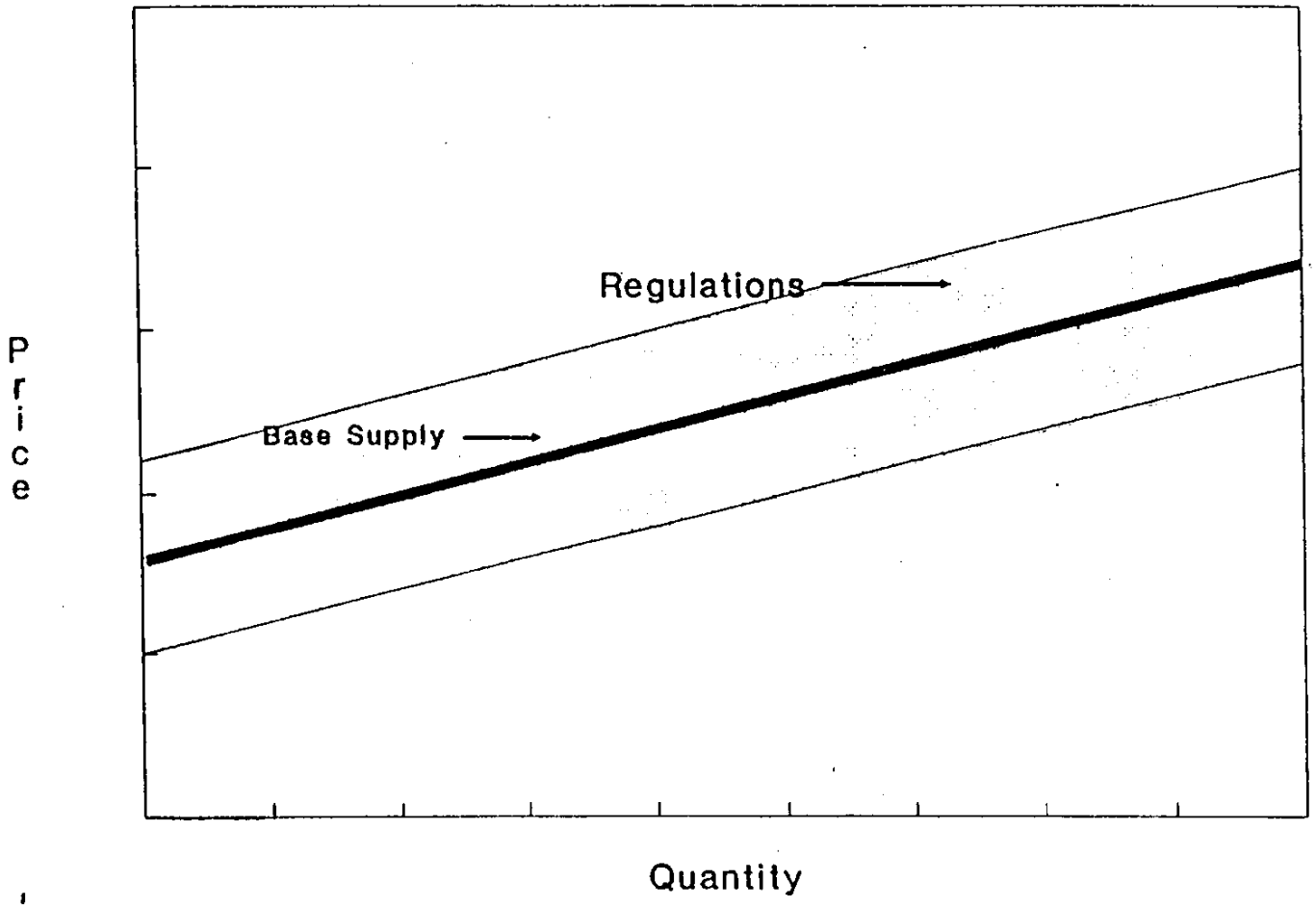


FIGURE III-11

SUPPLY/DEMAND BALANCE

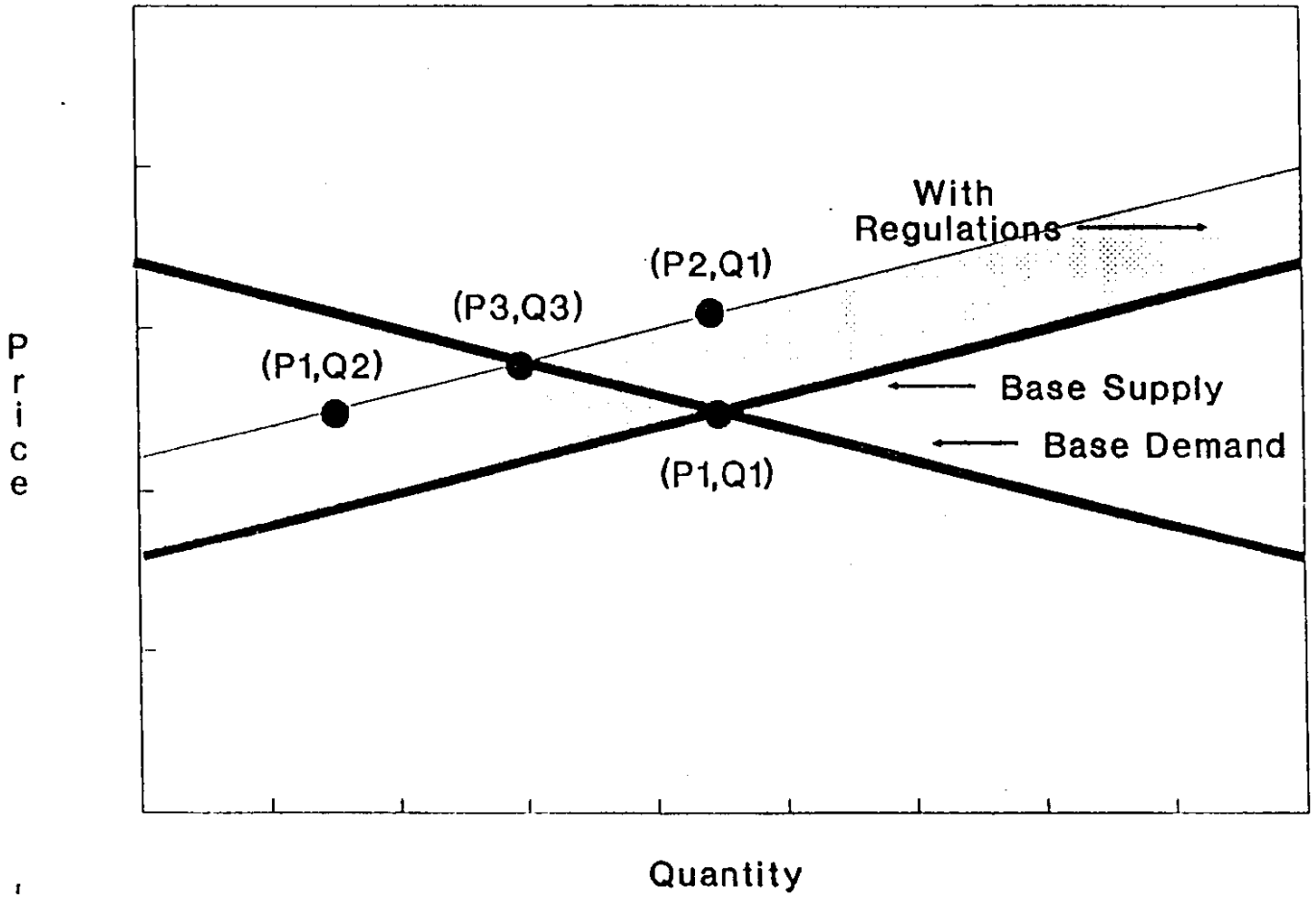
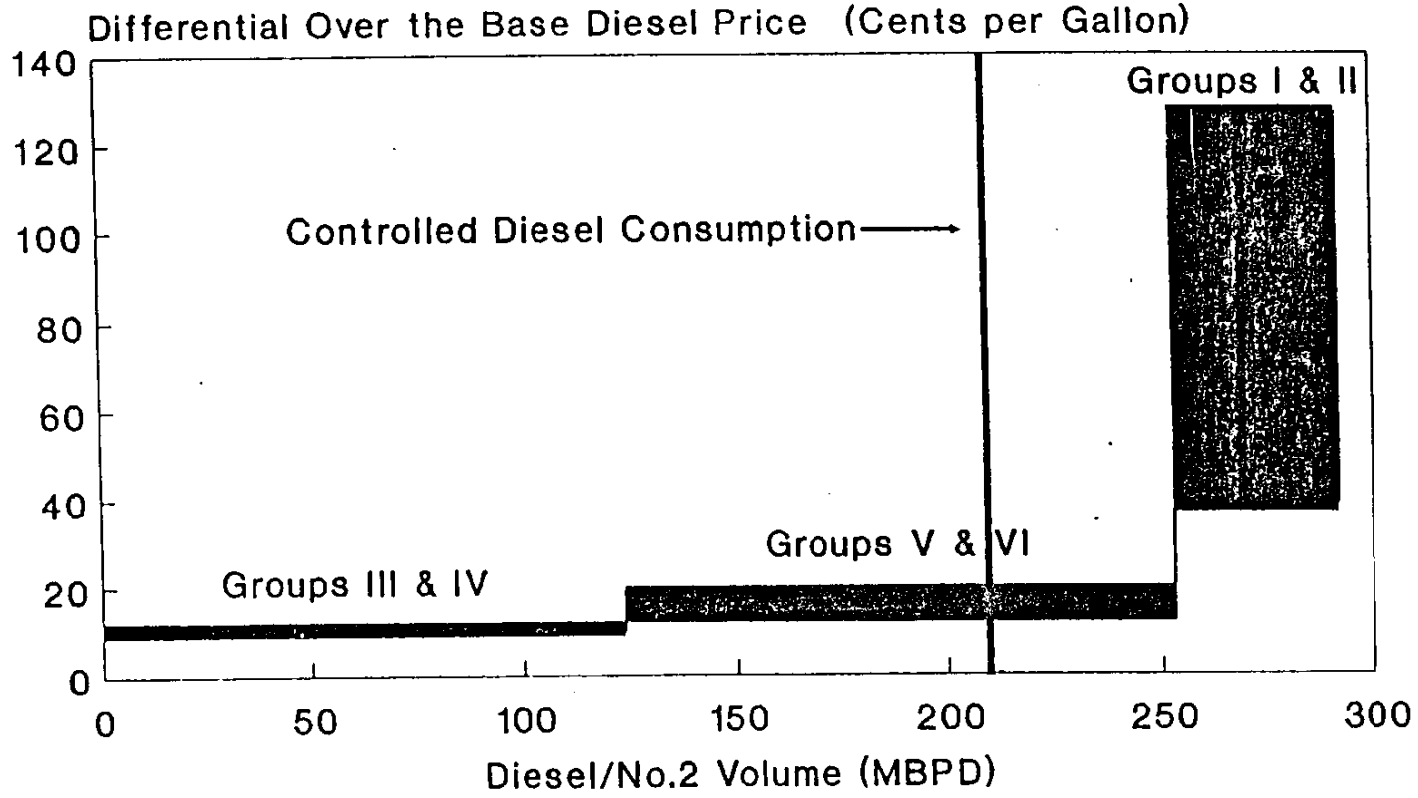


FIGURE III-12

CALIFORNIA DIESEL SUPPLY

ADDITIONAL COST OF LOW AROMATICS DIESEL

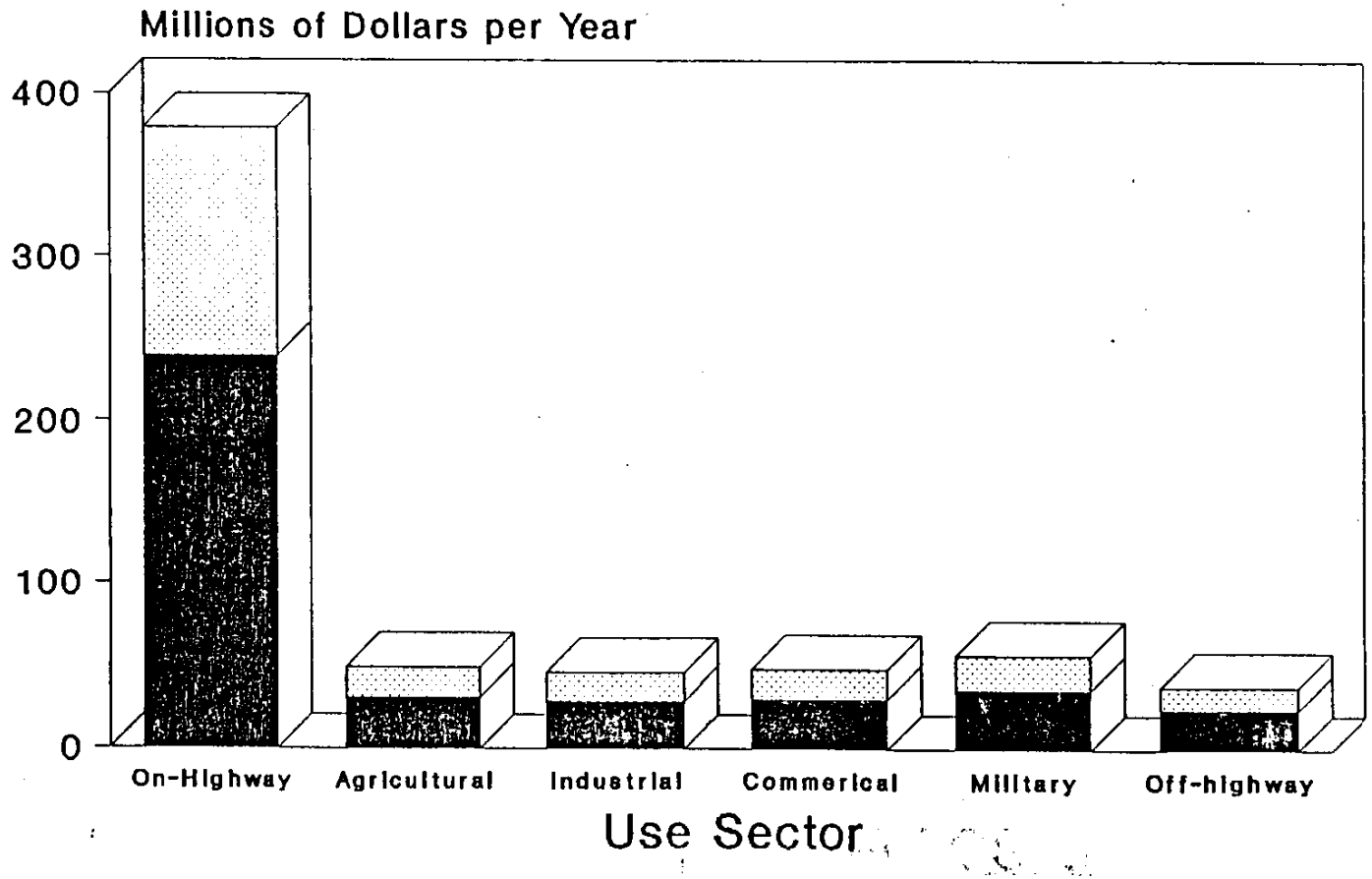


Source: Cost vs Supply data from ADL report
: "Cost of Reducing Aromatics & Sulfur Levels in Motor Vehicles"
Consumption Data from Purvin & Gertz

FIGURE III-13

LOW SULFUR/LOW AROMATICS DIESEL

IMPACT ON CONSUMERS



Based on 1986 consumption and ADL costs

LOW AROMATICS DIESEL

Prepared For

Western Oil & Gas Association

27 September 1988

Thomas J. Manning
John H. Vautrain

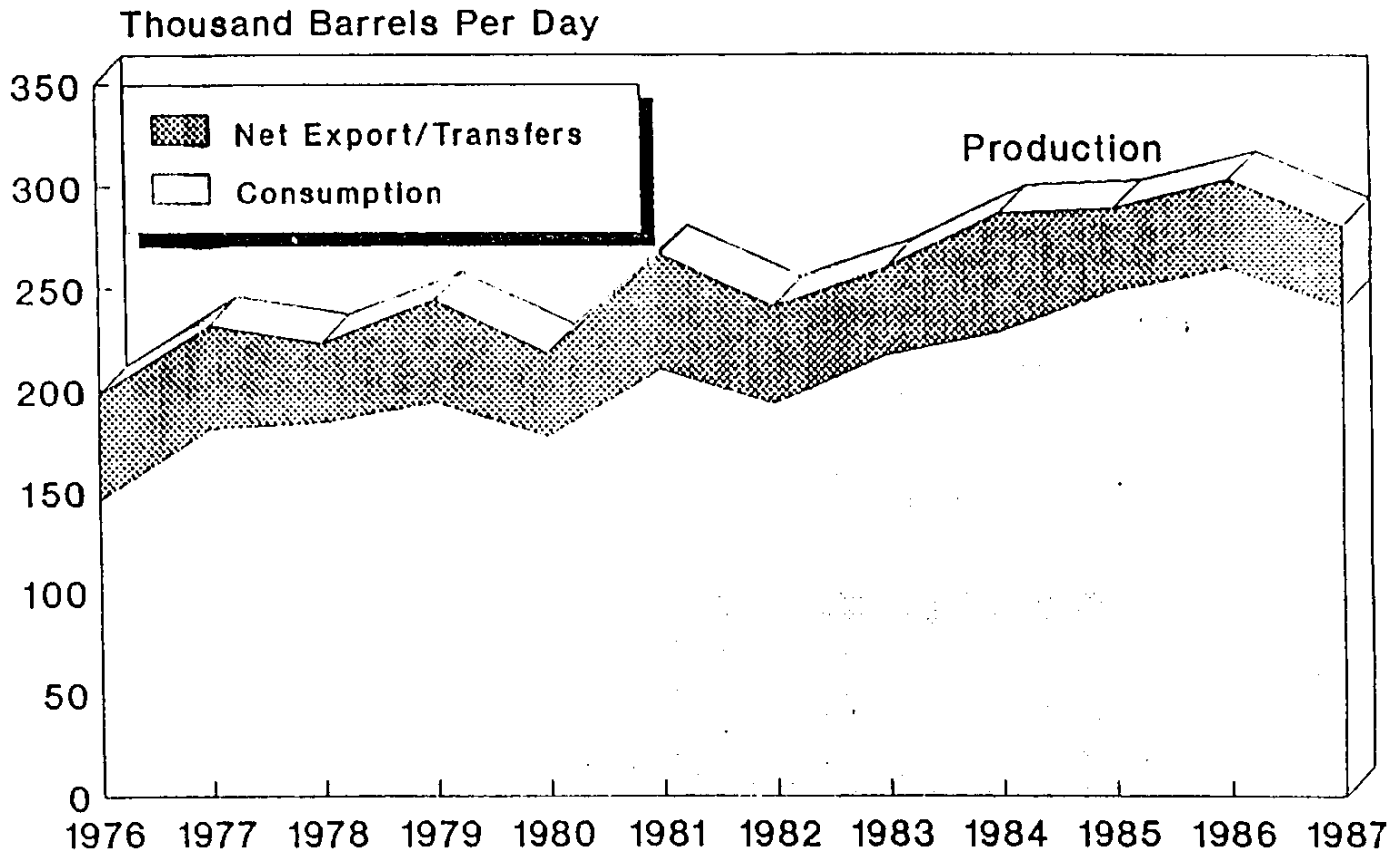
LOW AROMATICS DIESEL

AGENDA

- Distillate Supply/Demand
- External Sources
- Pricing Theory
- Impact of Low Aromatics Rule
- Conclusions

CALIFORNIA DISTILLATE

SUPPLY/DEMAND BALANCE

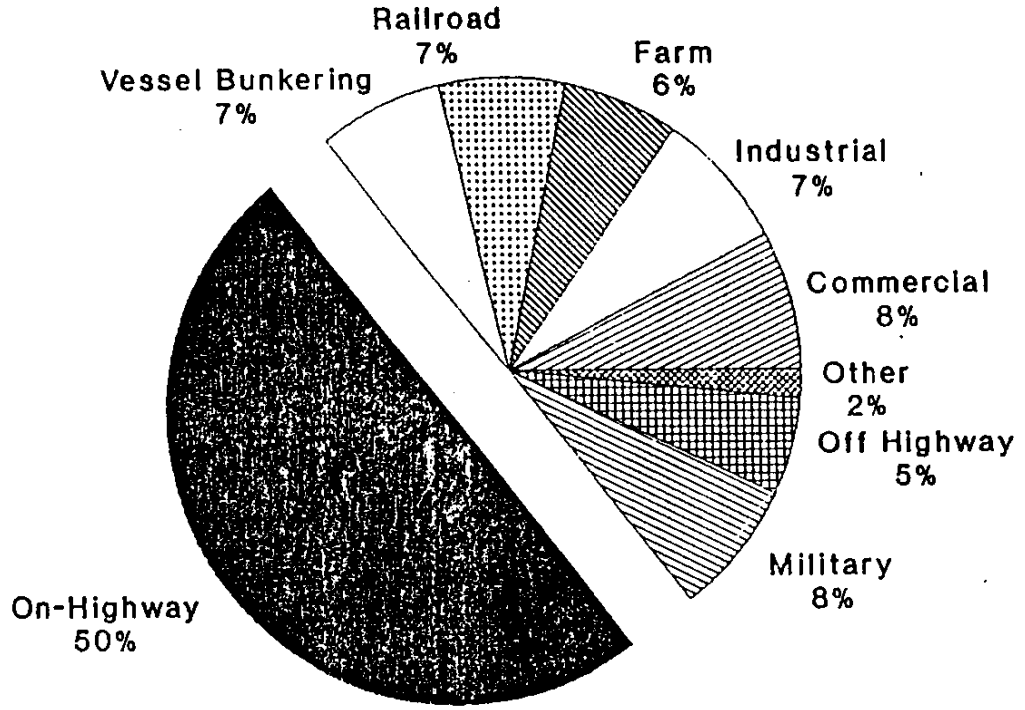


Source: California Energy Commission, Quarterly Reports

CALIFORNIA DISTILLATE/DIESEL FUEL

CONSUMPTION BY SECTOR: 1986

Percent

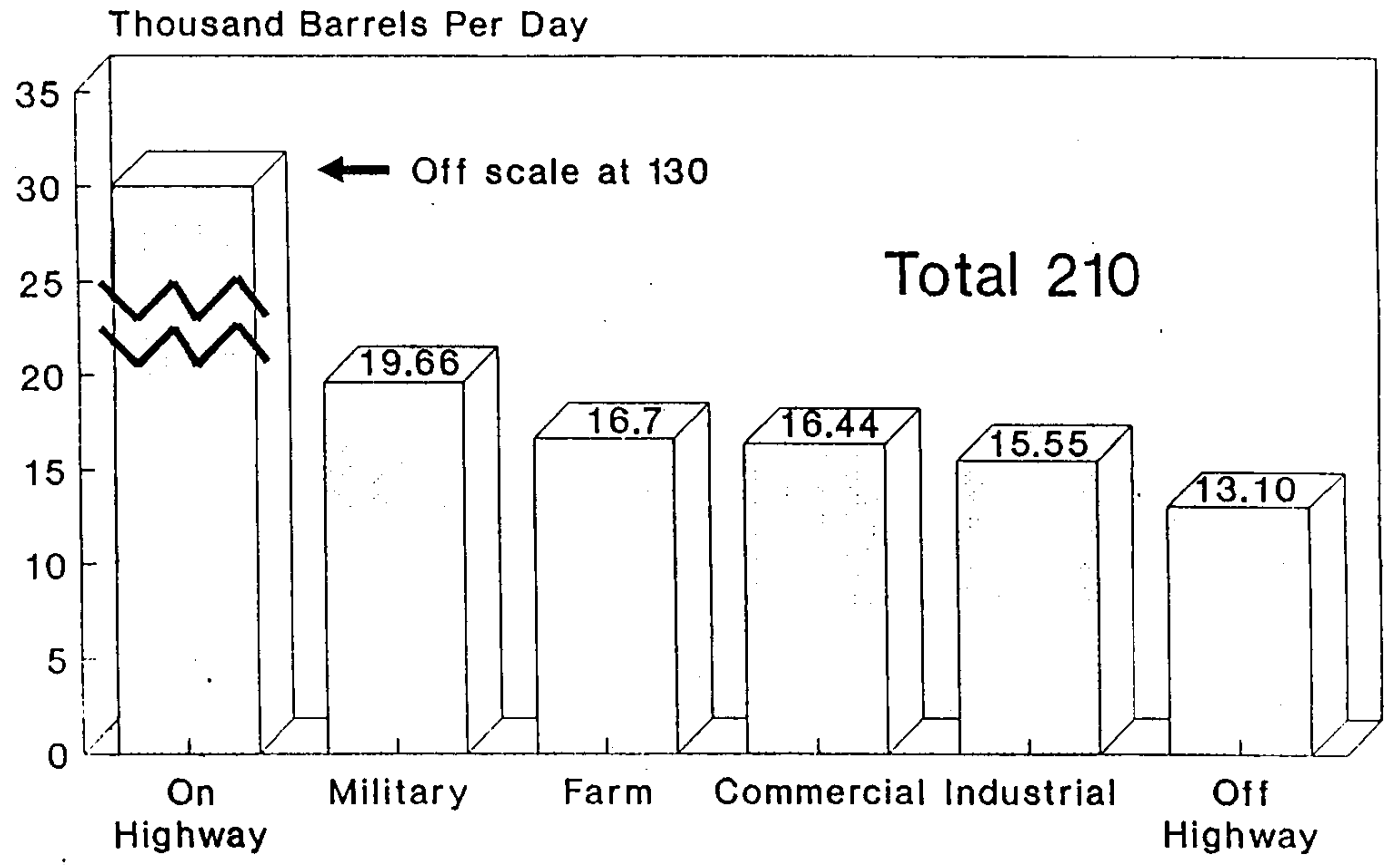


Source: DOE, Petroluem Marketing Monthly

PETRYN & GERTZ, INC.

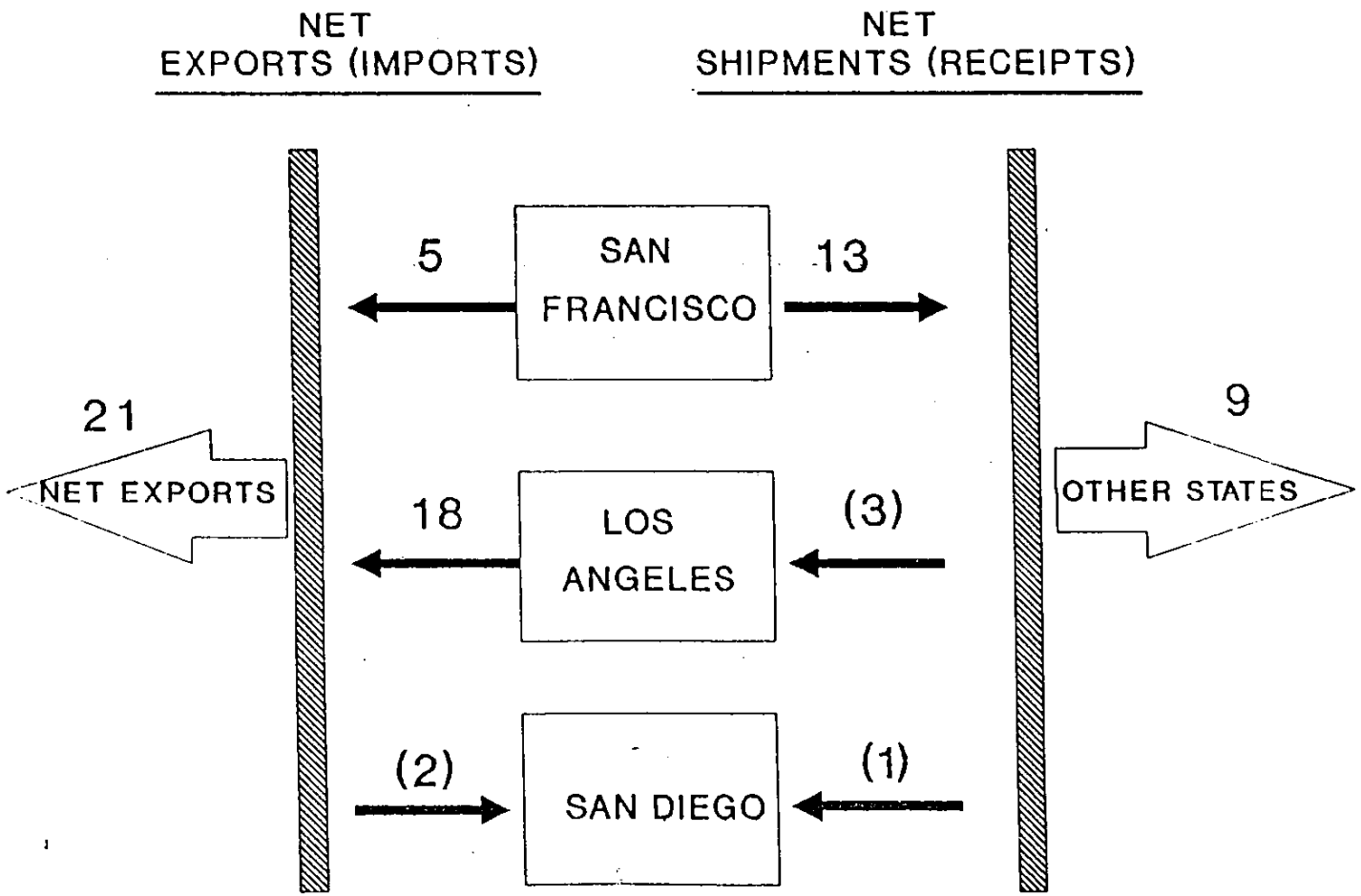
CALIFORNIA DIESEL FUEL

CONSUMPTION BY SECTOR: 1986

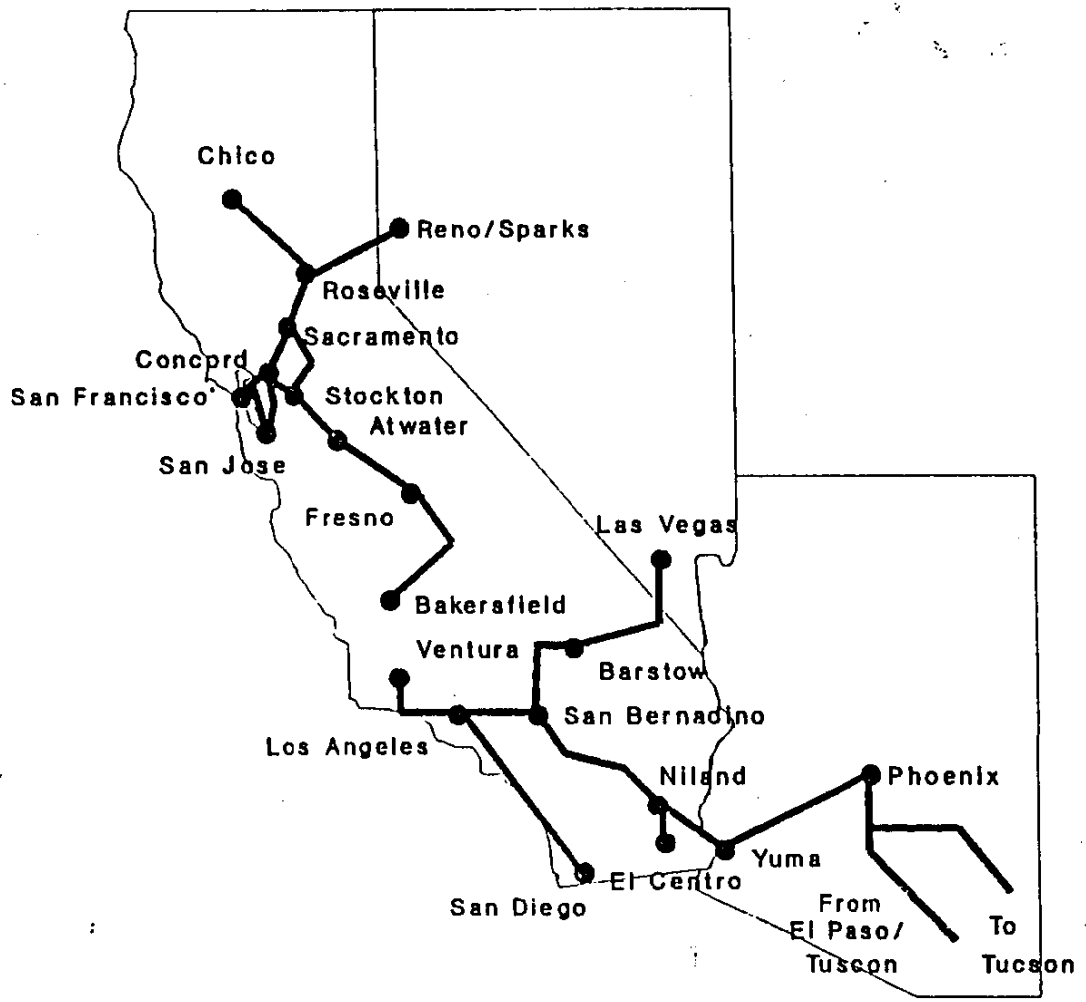


WATERBORNE SHIPMENTS OF DISTILLATE

EXPORTS AND DOMESTIC SHIPMENTS (MB/D)

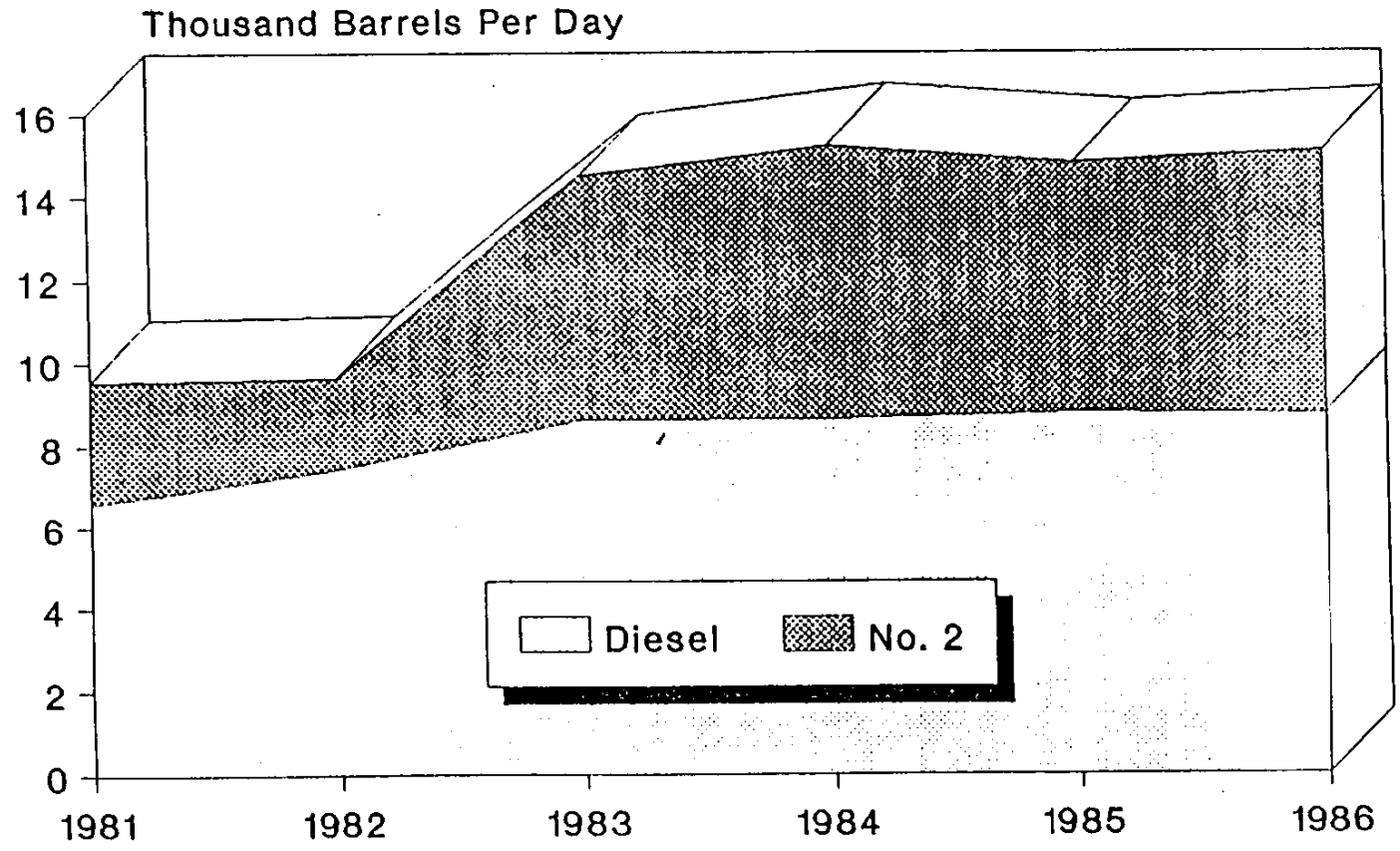


MAJOR PRODUCT PIPELINE SYSTEMS



NEVADA DISTILLATE CONSUMPTION

CONSUMPTION

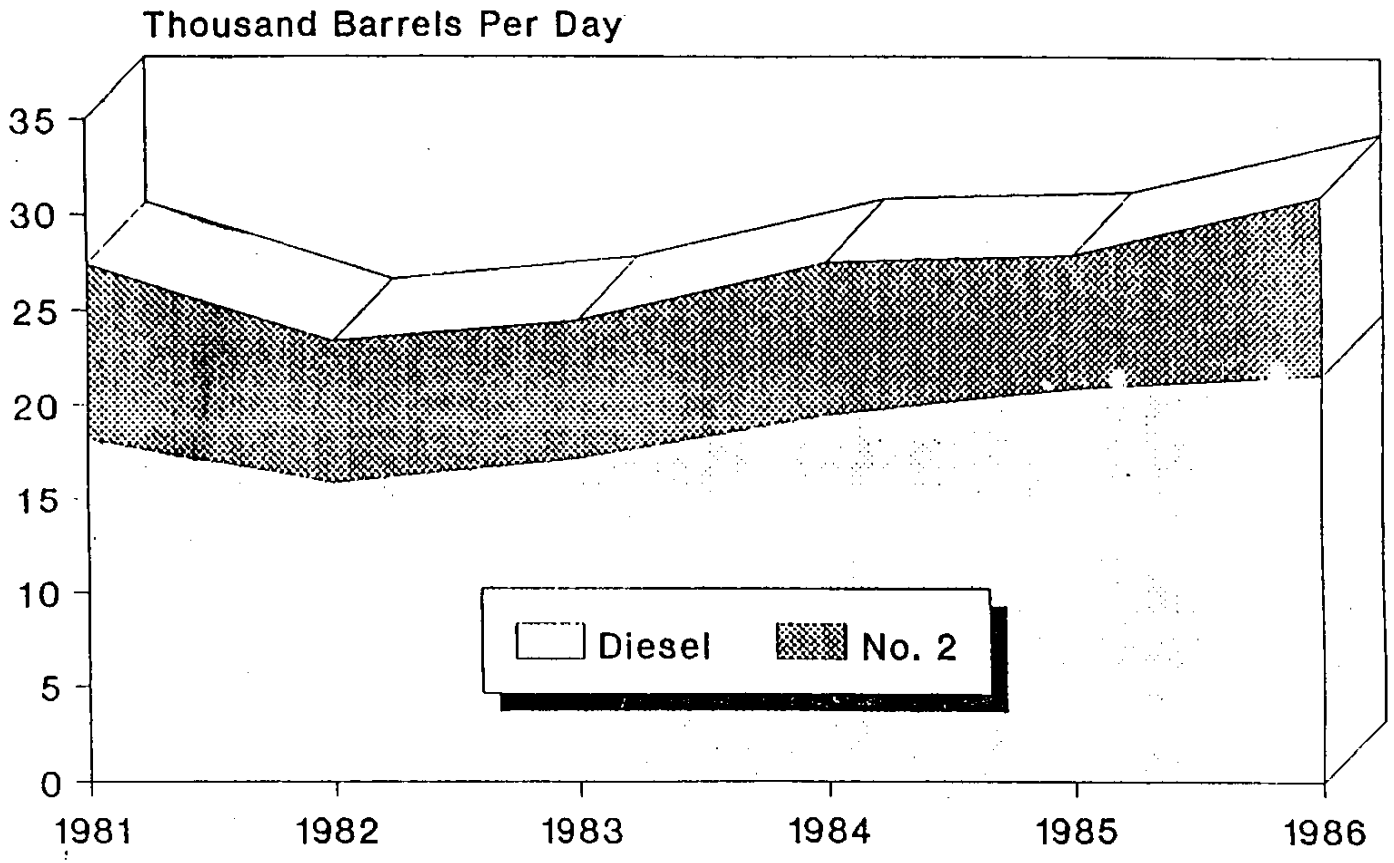


Source: DOE, Petroleum Marketing Monthly

PLEXUS & GERTZ, INC

ARIZONA DISTILLATE CONSUMPTION

CONSUMPTION

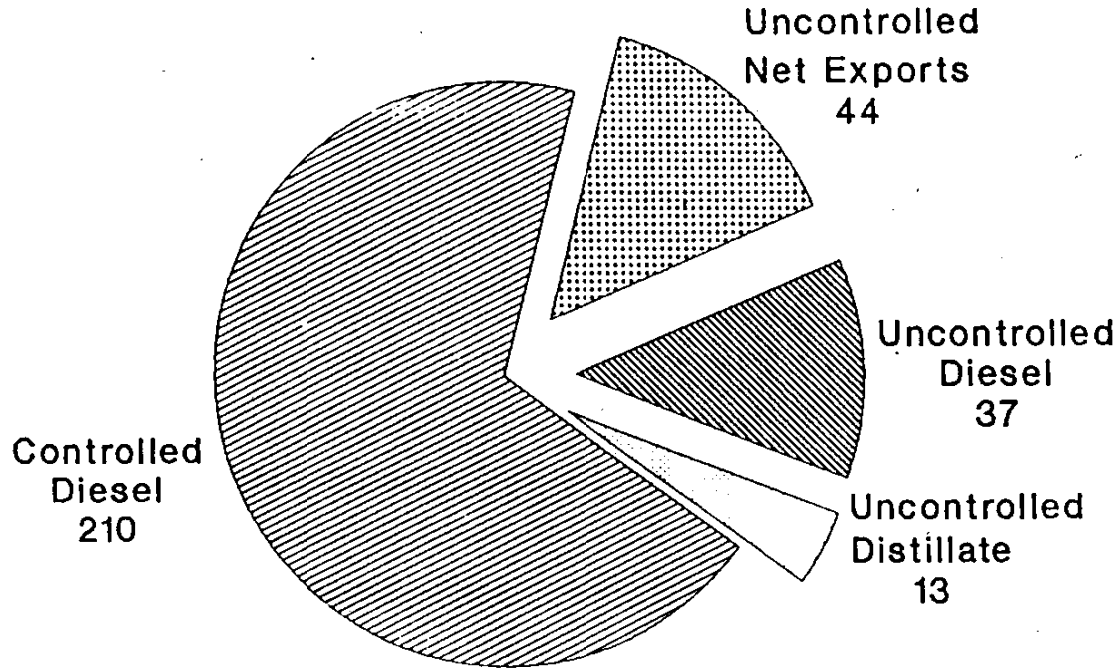


Source: DOE, Petroleum Marketing Monthly

CALIFORNIA DISTILLATE/DIESEL

PRODUCTION: 1986

Thousand Barrels Per Day



304 MB/D

Purvin & Gertz, Inc.

DIESEL BLENDSTOCKS

- Straight Run Distillates
- VGO Hydrocrackates
- FCC Cycle Oils
- Coker Distillates

STRAIGHT RUN DISTILLATES

QUALITY OF DISTILLATES

- MIDDLE EAST
  High aromatics, sour
- INDONESIA/MALAYSIA/FAR EAST
  Moderate aromatics but waxy crudes
- NORTH SEA/NORTHWEST EUROPE
  High aromatics, sweet
- U.S. GULF COAST
  Moderate to high aromatic
- PADD V/CALIFORNIA
  High aromatics, sour

Purvin & Gertz, Inc.

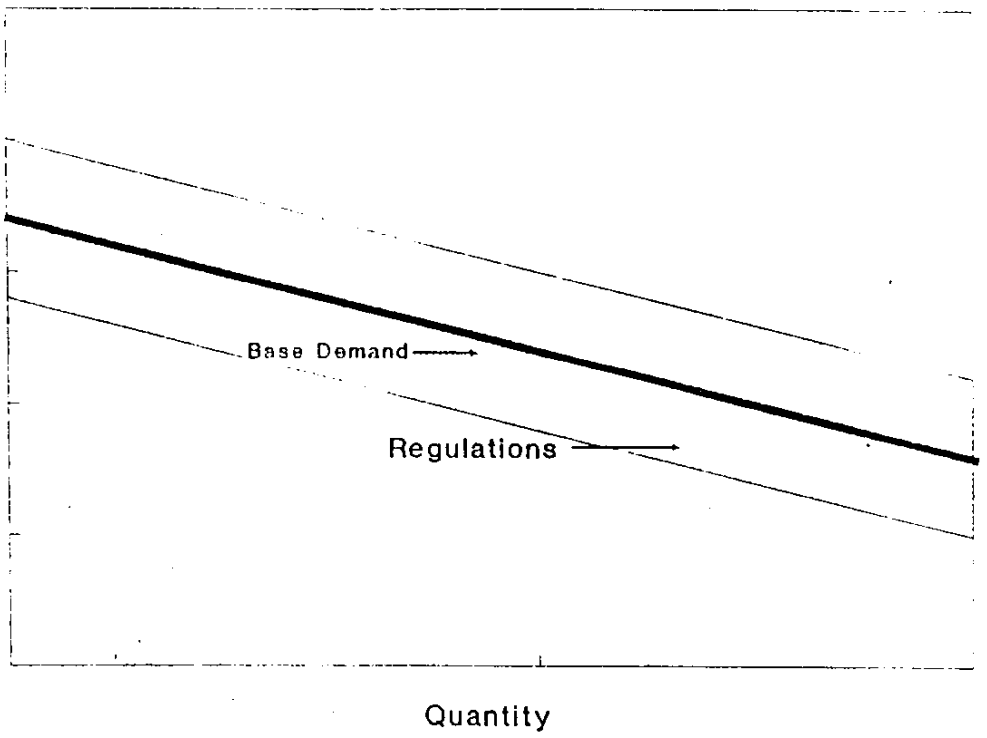
HYDROCRACKATES

- Ineffective for low-aromatics diesel production
- Hydrocrackates generally unavailable for export

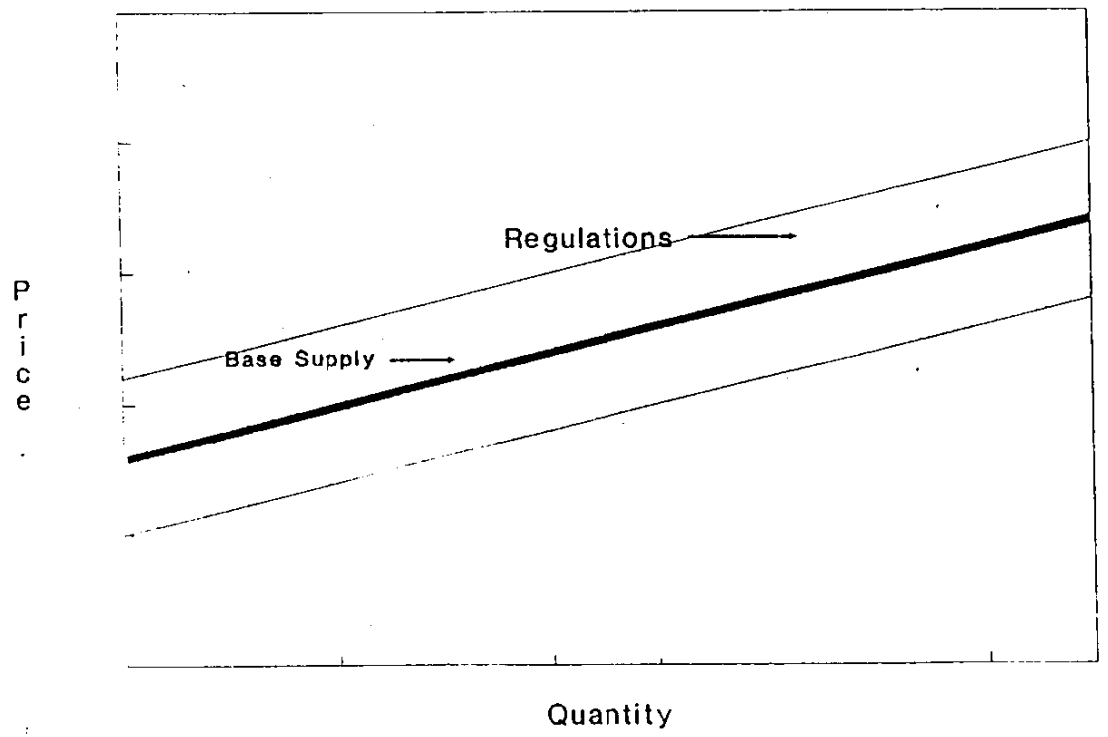
HIGH AROMATICS BLENDSTOCKS

- FCC CYCLE OILS
- COKER DISTILLATES

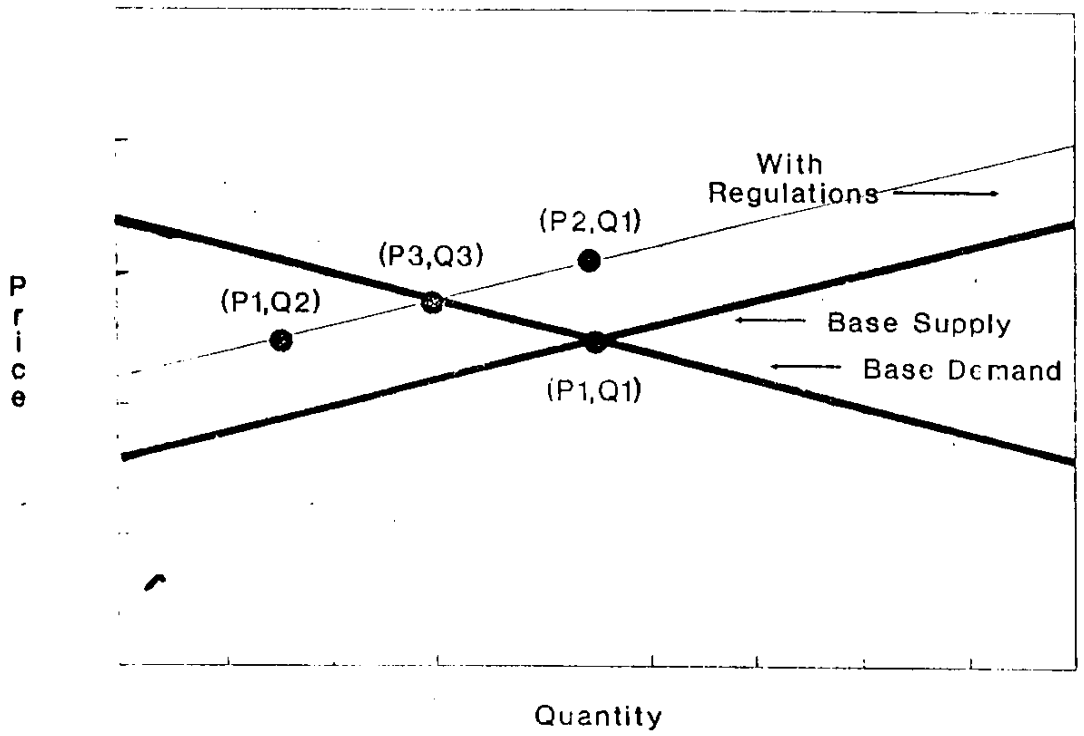
DEMAND ELASTICITY



SUPPLY ELASTICITY

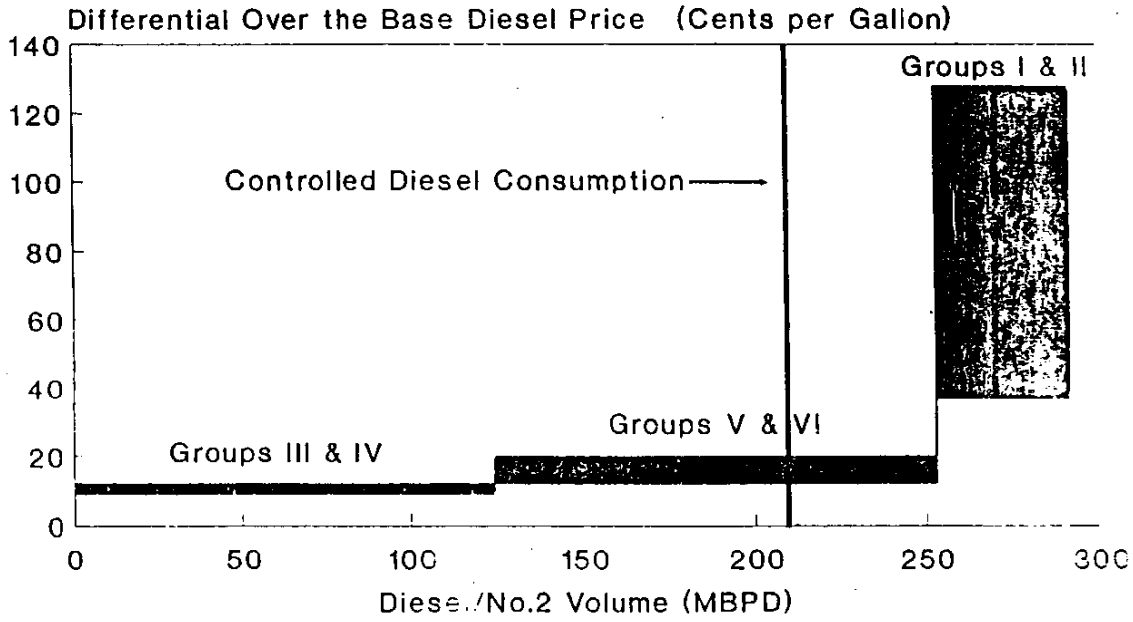


SUPPLY/DEMAND BALANCE



CALIFORNIA DIESEL SUPPLY

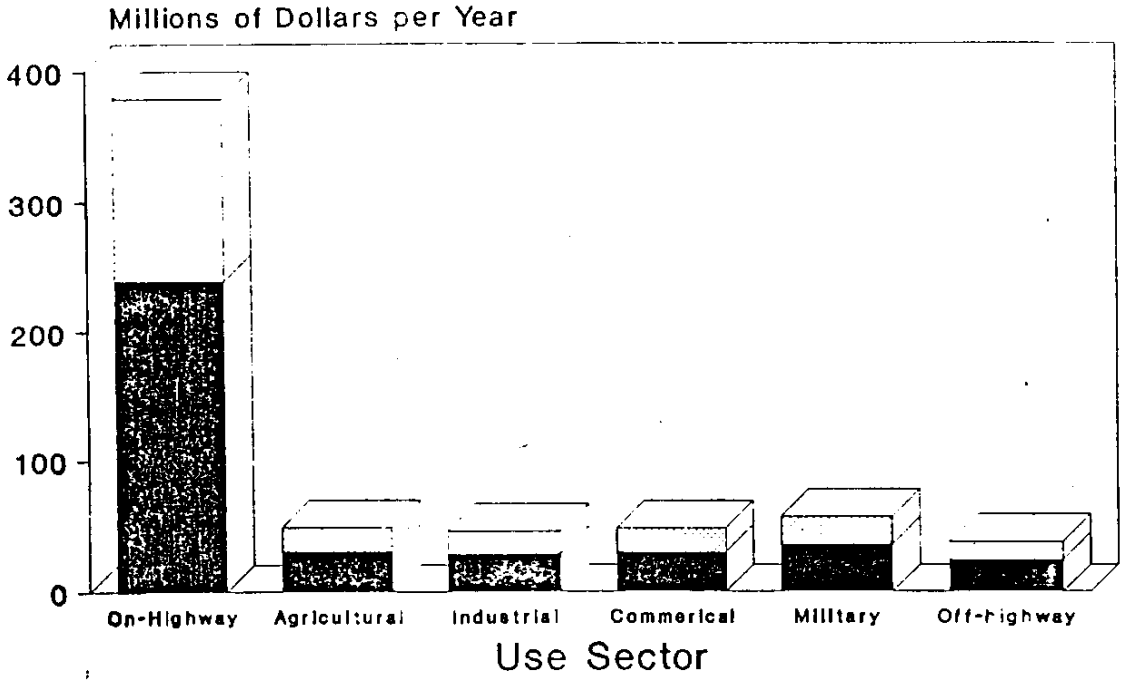
ADDITIONAL COST OF LOW AROMATICS DIESEL



Source: Cost vs Supply data from ADL report
"Cost of Reducing Aromatics & Sulfur Levels in Motor Vehicles"
Consumption Data from Purvin & Gertz

LOW SULFUR/LOW AROMATICS DIESEL

IMPACT ON CONSUMERS



Based on 1986 consumption and ADL costs

REVIEW AND EVALUATION OF CARB ANALYSES OF CRC-APRAC VE-1 DATA ON EFFECTS OF DIESEL FUEL PROPERTIES ON EXHAUST EMISSIONS OF MODERN HEAVY-DUTY DIESEL ENGINES

Prepared for Chevron Research Company
by Louis J. Painter, Statistical Consultant

Reviewed and endorsed by the
CRC-APRAC VE-1 Project Group.

SCOPE

This review and evaluation is based on the statistical analysis printouts provided by the CARB at the June 27, July 7, and August 5, 1988 "Consultation Meetings to Discuss Modification of Motor Vehicle Diesel Fuel Properties", and on the VE-1 Project Group Comments on the CARB analyses. Some comments can be made only in general terms as CARB did not obtain or provide printouts containing specific information on some points.

REVIEW OF CARB ANALYSES

The initial CARB analyses and plots of particulate matter, NOx and HC against just one experimental variable are quite inadequate as there were three variables in the experimental plan: FIA aromatics, sulfur, and 90% boiling point. The problem is that such plots are not very informative unless only one of the experimental factors has any substantial effect on the response (such as particulates) being analyzed.

The later analyses, printouts dated July 1-5, 1988, using all three variables are more appropriate, including as they do, all three experimental factors. Here, however, the plots would be better if they were of the form

Observed response (Y) vs. Fitted response (X) or

Residual (Observed - Fitted) vs. Fitted and/or each X.

(Note that the observed values (or residuals) are **NEVER** put on the horizontal axis. If this is done by mistake, a spurious correlation will appear to the eye.)

Plotting residuals (differences between observed and fitted values of the response variable) against the fitted values and also against the regressor variables gives a good overall indication of how adequate the fit is. Linear regression fits, as best it can, a plane through the data. If the data, on the scales used, are substantially curved, this will tend to show up on the residual plots as a "U" or banana shaped cloud of points. A good regression fit will have a residual plot that is cigar-shaped, and hopefully not too fat a cigar. Residual plots can also be very valuable in pinpointing aberrant data points, including data transcription errors.

I would also suggest looking at the use of the logarithms of the exhaust emission values in the regressions. This would be equivalent to plotting the data on semi-log paper. It would not change the particulate or NOx analyses much as the range of those data is not proportionately very great. The HC data analysis might well benefit from such treatment, however. Use of the logarithms might make the variances more nearly equal across the range of the HC data, in addition to making the effects percentage type effects.

Another point to consider in the models used to fit the data, is the possibility of interactions between the several experimental variables. The experimental layout should permit estimation and statistical evaluation of the two-factor interaction between sulfur and aromatics. The T90*aromatics interaction can only be estimated at high sulfur levels, while the T90*sulfur interaction effect is not at all possible, given the fuel design matrix.

In deciding which effects are statistically significant, CARB has apparently used the t-test probabilities provided in the SAS regression output. It must be kept in mind that these are two-sided statistical tests (PROB > |T|). Certainly for particulates, the concern is for the fact that high sulfur and high aromatics bring high particulates, not simply whether there is some effect of these variables, positive or negative, but rather is there a significant positive effect of these two factors. What would be decided if the aromatics effect on particulates were found to be negative? There would hardly be any incentive to require lower aromatics levels in diesel fuels!

What are the expected effects, to be guarded against, of each of the variables on each of the responses? These questions must be answered without reference to these data. And only then can statistical significance be estimated, based on whether one-sided or two-sided tests are considered appropriate.

For particulates, it would seem that one-sided tests for positive effects are appropriate. This leads to the following p-values for the sulfur effects:

Response	Engine	Sulfur Coeff.	p=PROB > T
PMCS	NTCC	0.196	0.026
PMCS	DDC	0.157	0.0003
PMHS	NTCC	0.067	0.066
PMHS	DDC	0.314	0.0001

Here we see that three of the four effects are quite significant while the fourth, PMHS NTCC, is almost there at the 5% level. It certainly doesn't miss by much.

The analysis done so far by CARB I would describe as piece-meal, looking at each engine separately, and also separately at the hot and cold start results. Should not the accepted EPA method of combining cold and hot start results (1 to 6 basis) be done? This would have the effect of averaging over some of the variability in the individual transient data, and reducing the dimensionality of the problem.

I strongly recommend that the analyses be done on a "global" basis. By that I mean fitting the data on all engines simultaneously, using an expanded model with terms for engine type and engine type by aromatics, engine type by sulfur, etc. interactions. This strengthens the analysis for all the effects, while still allowing for the possibility that some of the effects are different in different engines. It might also be found that use of the logarithmic transformation of the responses will eliminate the significance of any interaction effects.

A quick perusal of the data from this test program reveals that each fuel, in a given engine, was run over a relatively short time span, except for Fuel 5 which was tested many more times in small groups throughout the entire testing period. No attempt was made in the CARB analyses to adjust (account) for any time trends in the data. The Fuel 5 data should provide a good opportunity to make such adjustment, at least approximately. If any time trends exist in the data, and are not accounted for, the fuel effects will be badly compromised. My preliminary look at the Fuel 5 data shows no smooth trends, but rather a tendency to move up and down somewhat erratically with time. This is disconcerting as such behavior is difficult to adjust for.

Also, the uncertainty of any projected "benefit" of reduced sulfur and/or aromatics levels should be ascertained. This uncertainty is a direct reflection of the variability of the observed data and how far the proposed "regulation fuel" is from the center of the data base. Even the best estimate we can make of the uncertainty is an optimistic one, as the estimation procedure assumes that the mathematical form of the fitted equation (the variables and the scales used for them) is absolutely correct. This is hardly ever the case, unfortunately. Even a very good model is still only a reasonable approximation of the true state of nature.

COMMENTS ON VE-1 GROUP COMMENTS

I agree with the comment on fuel sulfur significance (see comments above). There is an important technical question here given the positive sulfur effect on particulates and the negative sulfur effect on NOx. If a one-sided negative significance test of sulfur effect on NOx is appropriate, than three of the four Cold/Hot Start, NTCC/DDC combinations give moderately significant negative sulfur effects.

From a purely statistical viewpoint, I would not necessarily agree that Cetane is an appropriate variable to bring in at this point in the analysis. The experimental design varied aromatics, sulfur, and T90. The question of whether Cetane Number (or Index) gives a "better" fit is almost irrelevant. The most important criterion for deciding which fuel variables should be used in the model for any particular response is: Does this variable make any technical/physical sense as something that would affect this response? To the extent that Cetane Number describes or affects peak temperatures in the combustion chamber, it may well be the proper variable for predicting, for example, NOx behavior. For other responses or for regulatory purposes, Cetane Number may prove to be a useful surrogate for some or

all of the experimental factors studied in the VE-1 program, but that should come later. This sort of problem crops up all the time when petroleum fuel property effects are being studied - most of such properties are tied together, none can be varied much at all without several others changing also. I would caution against slipping in surrogates too soon. But the best technical judgement should be given to deciding which variables are appropriate for which responses.

Lastly I agree that all the emissions should be looked at in the final analysis and very likely before any regulatory actions are taken. One need only look at the comparison of the particulate and NOx results: the overall sulfur effect seems to be opposite in sign for these two responses. Thus lowering sulfur to improve particulates might result in higher NOx emissions! What about CO and the other emission parameters? Although these are not of primary importance (and I understand that diesel CO emissions are extremely low), these other emissions were measured and should be examined to ensure that there are no surprises lurking among them.