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Preliminary Assessment of Future Refining Impacts of the Clean Air Act Amendments of 1990

G. R. Hadder

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

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DE92 003353

Energy Division

PRELIMINARY ASSESSMENT OF FUTURE REFINING IMPACTS OF THE CLEAN AIR ACT AMENDMENTS OF 1990

Principal Investigator

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Published September 1991

Report Prepared for

Office of Energy Demand Policy
Office of Policy, Planning and Analysis
U.S. Department of Energy

and

Navy Energy & Natural Resources Office
Office of Naval Research
Department of the Navy

Prepared by the
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MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACRONYMS AND ABBREVIATIONS

BOM	Bureau of Mines
CAA	Clean Air Act
CO	Carbon monoxide
C3/C4	Propane/butane
C5+	Pentanes and higher
DOE	Department of Energy
EIA	Energy Information Administration
FCC	Fluid catalytic cracker
gal	Gallon
MBD	Thousand barrels per day
MTBE	Methyl tertiary butyl ether
ORNL	Oak Ridge National Laboratory
OTM	Oil Trade Model
psi	Pounds per square inch, absolute
REMS	Refinery Evaluation Modeling System
RFG	Reformulated gasoline
RVP	Reid vapor pressure
RYM	Refinery Yield Model
SIP	State Implementation Plan

ACKNOWLEDGEMENTS

Support and technical guidance for this preliminary assessment of the refining impacts of the Clean Air Act have been provided by the Office of Energy Demand Policy of the Department of Energy and the Navy Energy & Natural Resources Office.

Throughout the development and application of the Navy Mobility Fuels Forecasting System used in this assessment, technical guidance has also been received from the Naval Air Propulsion Center and the David Taylor Naval Ship Research and Development Center. Insights on petroleum markets and refinery trends have been provided by the U.S. Oil & Refining Company; Tesoro Petroleum Corporation; the East-West Center Resource Systems Institute; Chevron U.S.A., Inc.; Pacific Resources, Inc.; the Amerada Hess Corporation; the Sun Company; Ashland Petroleum Company; Exxon Company, U.S.A.; Conoco, Inc.; Coastal Corporation; the National Petroleum Council; and the American Petroleum Institute. Technical guidance, data resources, and access to the principal forecasting models have been furnished by the Energy Information Administration, Department of Energy. ENSYS Energy & Systems, Inc., and Turner, Mason and Company have assisted in modification of the refinery models. Temple, Barker & Sloane, Inc., has provided input on petroleum logistics issues. This report was edited and typed by Jonnie Sorensen of Oak Ridge National Laboratory. The valuable contributions of these organizations and individuals are greatly appreciated.

ABSTRACT

A preliminary assessment of the future refining impacts of the Clean Air Act Amendments of 1990 has been performed with the Navy Mobility Fuels Forecasting System. The assessment suggests that gasoline reformulation costs in domestic coastal and near-coastal refining regions in the year 2000 could be 3.5 to 5.6 cents per gallon (in terms of 1989 currency). For heating value equivalent to one gallon of conventional gasoline, the regional total added costs (including reformulation costs) for reformulated gasoline could be 5.9 to 8.0 cents. In blending reformulated gasolines, the reduction of butane for lower Reid vapor pressure and the reduction of reformate for lower aromatics are generally compensated by increased percentages of alkylate and/or straight run naphthas. Relatively larger refinery process capacity additions are required for butane isomerization, alkylation, aromatics recovery, and distillate hydrotreating.

PRELIMINARY ASSESSMENT OF FUTURE REFINING IMPACTS OF THE CLEAN AIR ACT AMENDMENTS OF 1990

EXECUTIVE SUMMARY

The Clean Air Act Amendments of 1990 will affect refining more than any other industry because, in addition to complying with all other provisions of the Amendments, refiners will have to modify, design, permit, and construct new units to produce mandated clean fuels such as reformulated gasolines.

The law specifies a gasoline formula and also emission performance standards for reformulated gasolines, which are required by 1995 in nine areas with extreme or severe ozone pollution problems. The formula stipulates a minimum oxygen content; a maximum benzene content; a maximum aromatics content; no heavy metals; no increase in nitrogen oxide emissions; and reductions in ozone-forming volatile organic compounds and toxic emissions.

To investigate the future impacts of the Amendments on fuel production, the Office of Energy Demand Policy of the Department of Energy, the Navy Energy & Natural Resources Office, and Oak Ridge National Laboratory defined a business-as-usual scenario for the year 2000. Within the scenario, gasoline specifications were varied in several cases to estimate impacts on gasoline reformulation costs, refinery process capacity additions, gasoline composition, and the cost and quality of Navy fuels.

A preliminary assessment of the future refining impacts of the Amendments was performed with the Navy Mobility Fuels Forecasting System. The assessment suggests that in domestic coastal and near-coastal refining regions:

Gasoline reformulation costs in the year 2000 could be 3.5 to 5.6 cents per gallon (in terms of 1989 currency). For heating value equivalent to one gallon of conventional gasoline, the regional total added costs (including reformulation costs) for reformulated gasoline could be 5.9 to 8.0 cents.

In blending reformulated gasolines, the reduction of butane for lower Reid vapor pressure and the reduction of reformate for lower aromatics are generally compensated by increased percentages of alkylate and/or straight run naphthas.

Relatively larger refinery process capacity additions are required for butane isomerization, alkylation, aromatics recovery, and distillate hydrotreating.

The relative value of the oxygenate MTBE appears to be the most important determinant of the cost of reformulation. *MTBE cost sensitivity analysis is recommended for future studies of gasoline reformulation costs.*

The assessment focused on the effects of changes in Reid vapor pressure, oxygen content, aromatics content, and benzene content of gasoline. In the year 2000, vehicular emissions of volatile organic compounds, nitrogen oxides, and toxic compounds will be determined by statistically estimated models which will probably include the effects of oxygen content, aromatics content, sulfur content,

olefins content, and the 90 percent distillation temperature of gasoline. *It is recommended that future studies of reformulation describe gasolines in terms of all independent variables expected to be in the emission performance models of the year 2000.*

The regional refinery models used in the assessment assume that all refineries within a large region are interconnected. Consequently, the models have a tendency to over-optimize refinery operations. It has been demonstrated that disaggregation of refinery complexity classes reveals important differences in product producibility and process requirements which go undetected at the aggregate level. *It is recommended that, to the extent permitted by data availability, refinery complexity class disaggregation should be a feature of future studies of gasoline reformulation.*

1. THE CLEAN AIR ACT AMENDMENTS OF 1990

The Clean Air Act Amendments of 1990 (CAA) will affect refining more than any other industry because, in addition to complying with all other CAA provisions, refiners will have to modify, design, permit, and construct new units to produce mandated clean fuels. There are programs in the CAA for oxygenated gasoline and for reformulated gasoline (RFG).

The oxygenated gasoline program requires that, beginning November 1, 1992, gasoline with a minimum oxygen content of 2.7 weight percent must be sold during winter months in about 40 cities not in compliance with carbon monoxide (CO) standards.

RFGs are required by January 1, 1995, in nine areas with extreme or severe ozone pollution problems. About 100 other cities with marginal, moderate, or serious ozone problems may "opt-in" to the RFG program. The law specifies a formula for RFG and also an emission performance standard. The formula includes requirements for:

A minimum oxygen content of 2 weight percent.

A maximum benzene content of 1 volume percent (the current benzene content of gasolines averages 1.53 volume percent).

A maximum aromatics content of 25 volume percent (the current aromatics content of gasolines averages 32 volume percent).

No additives with heavy metals.

No increase in nitrogen oxide emissions compared to present gasolines.

A 15 percent reduction in ozone-forming volatile organic compounds, compared to 1990 levels. Beginning in the year 2000, volatile organic compounds and toxic emissions are required to be at least 20 percent below 1990 levels.[1]

The nine areas in the extreme and serious ozone nonattainment categories currently comprise about 25 percent of the nation's gasoline market. However, because of the gasoline distribution system, surrounding areas will probably receive RFG as well. Taking these surrounding areas into consideration, the minimum market for RFG in 1995 is expected to be 30 percent of the current market.

Other areas are allowed to petition the Environmental Protection Agency to opt-in to the oxygenated and RFG programs. The most likely areas to request clean gasolines are the other less severe ozone and CO non-attainment areas, which account for 20 to 35 percent of current gasoline demand. A significant motivation to enter the programs will come in November 1993, when State Implementation Plans (SIPs) are required. In the SIPs, states will have to demonstrate their strategies for achieving compliance with clean air standards. Using clean gasolines to reduce vehicular emissions could be more attractive than other alternatives. The total market for clean gasolines is uncertain, but it could exceed 50 percent by 1996-1997.[1]

The CAA also limits highway diesel fuel to a maximum sulfur content of 0.05 weight percent and a minimum cetane index of 40, effective October 1, 1993.[2]

With the passage of the CAA, environmental regulations will dictate the market, define product composition and performance, influence technology, change consumer expectations of performance, and determine the feasibility of various production and supply options.[1] In short, domestic refinery operations will be driven by environmental regulations, not by the consumer.

To investigate the future impacts of the CAA on fuel production, the Office of Energy Demand Policy of the Department of Energy, the Navy Energy & Natural Resources Office, and Oak Ridge National Laboratory defined a business-as-usual scenario for the year 2000.[3] Within the scenario, gasoline specifications were varied in several cases to estimate impacts on gasoline reformulation costs, refinery process capacity additions, gasoline composition, and the cost and quality of Navy fuels.

2. FORECASTING SYSTEM AND KEY ASSUMPTIONS

The preliminary assessment of future refining impacts of the CAA was performed with the Navy Mobility Fuels Forecasting System. The forecasting system, shown conceptually in Figure 1, consists of two Department of Energy models:

The Oil Trade Model (OTM) is a personal-computer-based, static, non-linear programming model which simulates world petroleum activities. Seven types of crude oils and eight types of refined products are produced and traded among the ten geographic regions of OTM. OTM balances petroleum supply and demand by maximizing consumer and producer surpluses, as constrained by world petroleum refining and distribution capabilities.[4] Crude oil supplies and the production of refined products are forecast by OTM for input to the Refinery Yield Model (RYM).

RYM is a personal-computer-based linear program[5,6] that represents regional refining operations. RYM includes 37 refinery processes, which can be used to produce over 30 products from at least 100 crude oils. Most of the RYM petroleum products are described by detailed quality specifications.

The OTM produces an aggregated picture of regional refining for different market scenarios. Although regional refining models are embedded within the OTM, they do not explicitly represent the production of reformulated fuels and military fuels. Therefore, RYM, which contains enhanced descriptions of fuel production, is independently executed using key results of OTM. The stand-alone RYM can be used to evaluate many variations of the refining environment. For example, RYM can produce detailed information on the effects of varying the specifications of reformulated fuels.

The OTM was used to analyze global petroleum markets in the year 2000 for a business-as-usual scenario based on Department of Energy projections of domestic and foreign supply and demand.[7,8] It was assumed that China, Eastern Europe, and the Soviel Union have free market economies for the purposes of international trade.

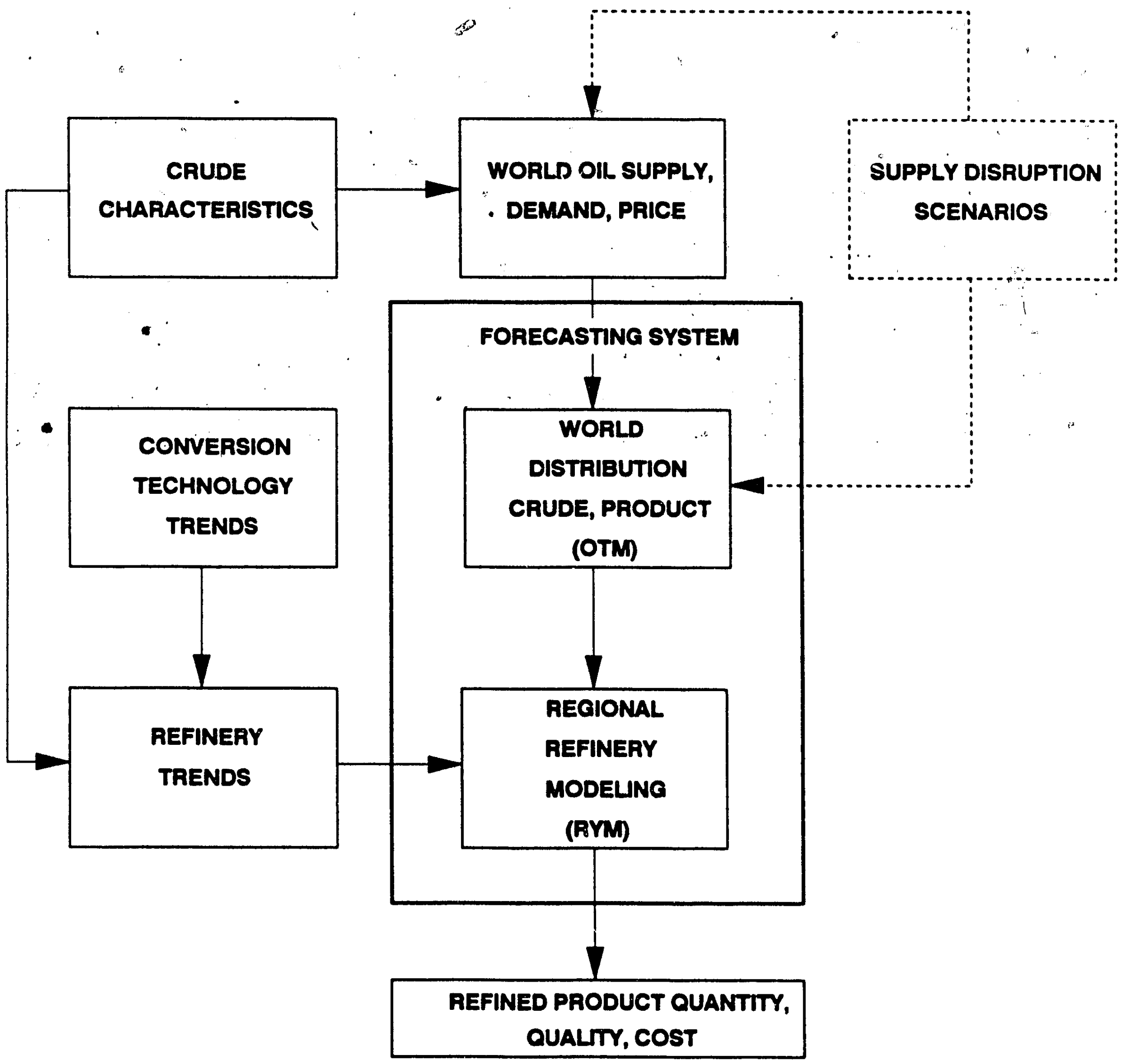
Key RYM assumptions for domestic refining regions in the year 2000 included the following:

RFG will have no lead; aromatics content will be limited to 25 volume percent maximum; benzene content will be limited to 1 volume percent maximum; and oxygen content will be limited to 2 weight percent minimum.[2] The Reid vapor pressure (RVP) blending target of summer RFG will vary from 7.0 to 8.7 psi.

Conventional gasoline will have maximum limits for aromatics (32 volume percent) and benzene (1.53 volume percent) set at the current average levels, to be consistent with the anti-dumping provisions of the CAA. These provisions require that the emissions of conventional gasoline must not exceed the emissions of gasoline produced in 1990. The RVP blending target for summer conventional gasoline will vary from 8.7 to 9.7 psi.

Domestic civilian highway diesel fuel will be restricted to 0.05 weight percent maximum sulfur and a minimum cetane index of 40.[2,9-12] The maximum aromatics content of diesel fuel will be limited to the current average of 34 volume percent.

FIGURE 1



Navy Mobility Fuels Forecasting System and supporting activities

U.S. military forces will convert from the use of naphtha jet fuel JP-4 and ground diesel fuel to the use of kerosene jet fuel JP-8.[13,14]

3. REGIONAL FUEL PRODUCTION

Refinery Yield Model studies were performed for domestic coastal or near-coastal regions. These regions, all of which have recent histories of Navy fuel production, are:

U.S. Bureau of Mines (BOM) Districts 1 and 2 (Delaware, Georgia, New Jersey, New York, North Carolina, Pennsylvania, Virginia, and West Virginia).

BOM Districts 7 and 11 (Inland Texas and New Mexico).

BOM District 8 (Texas Gulf Coast).

BOM Districts 9 and 10 (Louisiana, Mississippi, Alabama, and Arkansas).

BOM District 13 (Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington).

Gasoline production in the year 2000 was modeled for four cases:

(1) Total gasoline production consists of conventional gasoline with a 9.7 psi RVP. This gasoline has properties similar to gasoline of summer 1989.[15] Actual gasoline blendstocks for summer 1989 are shown in Table 1. *Case (1) is the base case.*

(2) Gasoline production consists of 50 percent conventional gasoline with an 8.7 psi RVP. With allowance for blending margins, the 8.7 psi RVP is consistent with the CAA requirements for conventional gasolines produced no later than the summer of 1992.[2] The other 50 percent of gasoline production is reformulated with an 8.7 psi RVP.

(3) Same as Case (2) except that RFG RVP has been reduced to 8.0 psi. With allowance for blending margins, the 8.0 psi RVP is consistent with CAA requirements for RFG produced in Volatility Class C areas until March 1997.

(4) Same as Case (2) except that RFG RVP has been reduced to 7.0 psi. With allowance for blending margins, the 7.0 psi RVP is consistent with CAA requirements for RFG produced in Volatility Class B areas until March 1997.

Study results for regional fuel production are presented in the following subsections. Readers less interested in fuel production details may prefer to skip the following subsections and proceed to the overview of results in Section 4.

Table 1. Average national gasoline blendstocks for summer 1989[15]

Blendstock	Percent
Butane	3.10
Reformate	27.22
Straight run naphtha	3.69
C5+ isomerate	3.68
FCC naphtha	38.04
Coker naphtha	0.68
Hydrocrackate	2.43
Alkylate	12.24
Polymer gasolines	0.28
Dimate	0.14
MTBE	0.81
Toluene/xylene	0.92
Natural gasoline	0.52
Pyrolysis gasoline	0.29
Raffinates	1.14
Other	4.81

3.1 GASOLINE PRODUCTION IN U.S. BUREAU OF MINES DISTRICTS 1 AND 2 (Delaware, Georgia, New Jersey, New York, North Carolina, Pennsylvania, Virginia, and West Virginia)

Gasoline reformulation costs in BOMs 1 & 2 are summarized for the four cases in Table 2. The gasoline reformulation cost assumes that any difference in refinery net margin between the base case and a reformulation case would be assigned to the cost of gasoline reformulation. Compared to the base case, the reformulation cost for 7.0 psi RVP gasoline is 3.8 cents per gallon (all costs are expressed in 1989 currency).

Table 3 shows that, compared to process capacity for the base case, the production of RFG requires additional capacity in alkylation, butane isomerization, aromatics recovery, distillate hydrotreating, solvent deasphalting, and hydrogen production.

Blendstocks for the base case output of conventional gasoline and for the case of 50:50 production of conventional gasoline and 7.0 psi RVP RFG are shown in Table 4. The reduction of butane for lower RVP and the reduction of reformate for lower aromatics are compensated by increased percentages of straight run naphtha and alkylate. MTBE and a small percentage of heavier ethers satisfy the oxygen requirement of RFG.

The reformulation cost of 3.8 cents per gallon does not account for blendstock effects on gasoline heating value. A gallon of 9.7 psi RVP conventional gasoline has about the same heating value as 1.03 gallons of 7.0 psi RVP RFG produced in BOMs 1 & 2.[16] The additional 0.03 gallon of RFG costs 2.4 cents. For heating value equivalent to one gallon of base case conventional gasoline, the total added cost (including reformulation cost) for RFG is 6.2 cents.

The regional refinery models used in the preliminary assessment assume that all refineries within a large region are interconnected. Consequently, the models have a tendency to over-optimize refinery operations. For example, over-optimization may contribute to under-investment in process capacity and to over-blending of butane in gasoline. The over-optimization problem can sometimes be mitigated by focusing on changes in refining variables, rather than relying on the model to predict the exact value of variables for a particular case.

Table 2. Year 2000 gasoline reformulation cost for different RVP gasolines produced in BOMs 1 & 2

RVP Conventional/RFG (psi)/(psi)	Gasoline reformulation cost (cents/gal)
9.7/NA	NA
8.7/8.7	3.5
8.7/8.0	3.5
8.7/7.0	3.8

Table 3. Capacity additions in BOMs 1 & 2 to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	9.2
Butane isomerization	12.9
Aromatics recovery	6.9
Distillate hydrotreating	4.6
Solvent deasphalting	4.7
Hydrogen production	0.8

Table 4. Gasoline blendstocks in BOMs 1 & 2 for the year 2000 (percent)			
	100 Percent conventional gasoline production	50 Percent conventional and 50 percent RFG production	
Blendstock	Conventional gasoline 9.7 psi RVP	Conventional gasoline 8.7 psi RVP	RFG 7.0 psi RVP
Butane	4.76	2.48	0.34
Reformate	25.35	24.29	15.17
Straight run naphtha	8.67		20.07
C5+ isomerate	3.07	6.14	
FCC naphtha	36.09	43.81	33.04
Coker naphtha			
Hydrocrackate	2.43	4.73	1.50
Alkylate	13.04	11.72	18.60
Polymer gasolines	3.02	1.74	
Dimate	0.76		
MTBE			11.16
Toluene/xylene			
Natural gasoline			
Pyrolysis gasoline			
Raffinates			
Other	2.81	5.09	0.12

3.2 GASOLINE PRODUCTION IN U.S. BUREAU OF MINES DISTRICTS 7 AND 11 (Inland Texas and New Mexico)

Gasoline reformulation costs in BOMs 7 & 11 are summarized for the four cases in Table 5. Compared to the base case, the reformulation cost for 7.0 psi RVP gasoline is 4.0 cents per gallon.

Table 6 shows that, compared to process capacity for the base case, the production of RFG requires additional capacity in alkylation, butane isomerization, visbreaking, FCC feed hydrofining, distillate hydrotreating, and solvent deasphalting.

Blendstocks for the base case output of conventional gasoline and for the case of 50:50 production of conventional gasoline and 7.0 psi RVP RFG are shown in Table 7. The reduction of butane for lower RVP and the reduction of reformate for lower aromatics are compensated by increased percentages of straight run naphtha, C5+ isomerate, and alkylate. MTBE satisfies the oxygen requirement of RFG.

The reformulation cost of 4.0 cents per gallon does not account for blendstock effects on gasoline heating value. A gallon of 9.7 psi RVP conventional gasoline has about the same heating value as 1.05 gallons of 7.0 psi RVP RFG produced in BOMs 7 & 11. The additional 0.05 gallon of RFG costs 4.0 cents. For heating value equivalent to one gallon of base case conventional gasoline, the total added cost (including reformulation cost) for RFG is 8.0 cents.

Table 5. Year 2000 gasoline reformulation cost for different RVP gasolines produced in BOMs 7 & 11

RVP Conventional/RFG (psi)/(psi)	Gasoline reformulation cost (cents/gal)
9.7/NA	NA
8.7/8.7	3.4
8.7/8.0	3.7
8.7/7.0	4.0

Table 6. Capacity additions in BOMs 7 & 11 to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	6.9
Butane isomerization	6.2
Visbreaking	1.0
FCC feed hydrofining	1.3
Distillate hydrotreating	0.4
Solvent deasphalting	4.5

Table 7. Gasoline blendstocks in BOMs 7 & 11 for the year 2000 (percent)

Blendstock	100 Percent conventional gasoline production	50 Percent conventional and 50 percent RFG production	
	Conventional gasoline 9.7 psi RVP	Conventional gasoline 8.7 psi RVP	RFG 7.0 psi RVP
Butane	4.90	2.01	0.69
Reformate	18.80	22.28	7.66
Straight run naphtha		3.17	6.59
C5+ isomerate	5.87		11.73
FCC naphtha	40.57	42.73	33.45
Coker naphtha			
Hydrocrackate	1.98	2.27	
Alkylate	19.75	15.42	28.61
Polymer gasolines	2.11	2.38	
Dimate	0.90		
MTBE	0.26		11.26
Toluene/xylene			
Natural gasoline			
Pyrolysis gasoline			
Raffinates			
Other	4.86	9.74	0.01

3.3 GASOLINE PRODUCTION IN U.S. BUREAU OF MINES DISTRICT 8 (Texas Gulf Coast)

Gasoline reformulation costs in BOM 8 are summarized for the four cases in Table 8. Compared to the base case, the reformulation cost for 7.0 psi RVP gasoline is 3.5 cents per gallon.

Table 9 shows that, compared to process capacity for the base case, the production of RFG requires additional capacity in alkylation, butane isomerization, C3/C4 dehydrogenation, and distillate hydrotreating.

Blendstocks for the base case output of conventional gasoline and for the case of 50:50 production of conventional gasoline and 7.0 psi RVP RFG are shown in Table 10. The reduction of butane for lower RVP and the reduction of reformate for lower aromatics are compensated by increased percentages of hydrocrackate and alkylate. MTBE satisfies the oxygen requirement of RFG.

The reformulation cost of 3.5 cents per gallon does not account for blendstock effects on gasoline heating value. A gallon of 9.7 psi RVP conventional gasoline has about the same heating value as 1.03 gallons of 7.0 psi RVP RFG produced in BOM 8. The additional 0.03 gallon of RFG costs 2.4 cents. For heating value equivalent to one gallon of base case conventional gasoline, the total added cost (including reformulation cost) for RFG is 5.9 cents.

Table 8. Year 2000 gasoline reformulation cost for different RVP gasolines produced in BOM 8

RVP Conventional/RFG (psi)/(psi)	Gasoline reformulation cost (cents/gal)
9.7/NA	NA
8.7/8.7	2.8
8.7/8.0	3.1
8.7/7.0	3.5

Table 9. Capacity additions in BOM 8 to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	15.5
Butane isomerization	31.6
C3/C4 dehydrogenation	1.6
Distillate hydrotreating	20.3

Table 10. Gasoline blendstocks in BOM 8 for the year 2000 (percent)			
	100 Percent conventional gasoline production	50 Percent conventional and 50 percent RFG production	
Blendstock	Conventional gasoline 9.7 psi RVP	Conventional gasoline 8.7 psi RVP	RFG 7.0 psi RVP
Butane	4.94	2.66	0.95
Reformate	24.75	30.03	10.73
Straight run naphtha	5.69	11.48	1.48
C5+ isomerate	3.28	1.83	4.73
FCC naphtha	35.27	31.24	33.57
Coker naphtha			
Hydrocrackate	3.96	2.74	13.24
Alkylate	13.96	8.77	24.03
Polymer gasolines	4.60	5.81	
Dimate			
MTBE	0.82		11.26
Toluene/xylene			
Natural gasoline			
Pyrolysis gasoline			
Raffinates			
Other	2.73	5.44	0.01

3.4 GASOLINE PRODUCTION IN U.S. BUREAU OF MINES DISTRICTS 9 AND 10 (Louisiana, Mississippi, Alabama, and Arkansas)

Gasoline reformulation costs in BOMs 9 & 10 are summarized for the four cases in Table 11. Compared to the base case, the reformulation cost for 7.0 psi RVP gasoline is 4.5 cents per gallon.

Table 12 shows that, compared to process capacity for the base case, the production of RFG requires additional capacity in alkylation, butane isomerization, C3/C4 dehydrogenation, aromatics recovery, and distillate hydrotreating.

Blendstocks for the base case output of conventional gasoline and for the case of 50:50 production of conventional gasoline and 7.0 psi RVP RFG are shown in Table 13. The reduction of butane for lower RVP and the reduction of reformate for lower aromatics are compensated primarily by an increased percentage of alkylate. MTBE satisfies the oxygen requirement of RFG.

The reformulation cost of 4.5 cents per gallon does not account for blendstock effects on gasoline heating value. A gallon of 9.7 psi RVP conventional gasoline has about the same heating value as 1.02 gallons of 7.0 psi RVP RFG produced in BOMs 9 & 10. The additional 0.02 gallon of RFG costs 1.6 cents. For heating value equivalent to one gallon of base case conventional gasoline, the total added cost (including reformulation cost) for RFG is 6.1 cents.

Table 11. Year 2000 gasoline reformulation cost for different RVP gasolines produced in BOMs 9 & 10

RVP Conventional/RFG (psi)/(psi)	Gasoline reformulation cost (cents/gal)
9.7/NA	NA
8.7/8.7	3.8
8.7/8.0	4.1
8.7/7.0	4.5

Table 12. Capacity additions in BOMs 9 & 10 to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	13.1
Butane isomerization	25.0
C3/C4 dehydrogenation	4.4
Aromatics recovery	27.1
Distillate hydrotreating	19.0

Table 13. Gasoline blendstocks in BOMs 9 & 10 for the year 2000 (percent)			
	100 Percent conventional gasoline production	50 Percent conventional and 50 percent RFG production	
Blendstock	Conventional gasoline 9.7 psi RVP	Conventional gasoline 8.7 psi RVP	RFG 7.0 psi RVP
Butane	4.97	1.91	1.27
Reformate	21.70	24.07	11.50
Straight run naphtha	5.54	10.08	2.93
C5+ isomerate	3.67		7.34
FCC naphtha	37.70	36.75	33.42
Coker naphtha			
Hydrocrackate	3.60	6.96	5.14
Alkylate	15.89	9.94	27.14
Polymer gasolines	3.88	4.19	
Dimate			
MTBE			11.26
Toluene/xylene			
Natural gasoline			
Pyrolysis gasoline			
Raffinates			
Other	3.05	6.10	

3.5 GASOLINE PRODUCTION IN U.S. BUREAU OF MINES DISTRICT 13 (Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington)

Gasoline reformulation costs in BOM 13 are summarized for the four cases in Table 14. Compared to the base case, the reformulation cost for 7.0 psi RVP gasoline is 5.6 cents per gallon.

Table 15 shows that, compared to process capacity for the base case, the production of RFG requires additional capacity in alkylation, butane isomerization, aromatics recovery, visbreaking, and MTBE production.

Blendstocks for the base case output of conventional gasoline and for the case of 50:50 production of conventional gasoline and 7.0 psi RVP RFG are shown in Table 16. The reduction of butane for lower RVP and the reduction of reformate for lower aromatics are compensated by increased percentages of straight run naphtha and alkylate. MTBE and a small percentage of heavier ethers satisfy the oxygen requirement of RFG.

The reformulation cost of 5.6 cents per gallon does not account for blendstock effects on gasoline heating value. A gallon of 9.7 psi RVP conventional gasoline has about the same heating value as 1.03 gallons of 7.0 psi RVP RFG produced in BOM 13. The additional 0.03 gallon of RFG costs 2.4 cents. For heating value equivalent to one gallon of base case conventional gasoline, the total added cost (including reformulation cost) for RFG is 8.0 cents.

Table 14. Year 2000 gasoline reformulation cost for different RVP gasolines produced in BOM 13

RVP Conventional/RFG (psi)/(psi)	Gasoline reformulation cost (cents/gal)
9.7/NA	NA
8.7/8.7	5.2
8.7/8.0	5.2
8.7/7.0	5.6

Table 15. Capacity additions in BOM 13 to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	39.1
Butane isomerization	30.9
Aromatics recovery	37.3
Visbreaking	3.3
MTBE	1.0

Table 16. Gasoline blendstocks in BOM 13 for the year 2000 (percent)			
	100 Percent conventional gasoline production	50 Percent conventional and 50 percent RFG production	
Blendstock	Conventional gasoline 9.7 psi RVP	Conventional gasoline 8.7 psi RVP	RFG 7.0 psi RVP
Butane	4.85	2.48	
Reformate	22.16	21.57	10.66
Straight run naphtha	4.96	8.90	10.23
C5+ isomerate	0.66		1.32
FCC naphtha	39.57	42.72	34.91
Coker naphtha			
Hydrocrackate	8.66	8.92	7.04
Alkylate	14.40	12.32	24.50
Polymer gasolines	3.18	1.99	
Dimate	0.11		
MTBE			11.10
Toluene/xylene			
Natural gasoline	0.92		
Pyrolysis gasoline			
Raffinates			
Other	0.53	1.10	0.24

3.6 DOMESTIC NAVY FUEL PRODUCTION

Oxygenates purchased for RFG ease the competition for blendstocks and reduce the marginal costs of domestically produced Navy fuels. As shown in Table 17, the forecasting system estimates that the marginal cost of domestic production of Navy fuels could decrease by as much as 5.2 cents per gallon during production of 7.0 psi RVP RFG.

Compared to the base case for total production of conventional gasoline, the case for production of 7.0 psi RVP RFG adversely affects Navy fuel quality only in BOMs 9 and 10. In this region:

JP-5 aromatics content increases 7 percent.

JP-5 smoke point decreases 9 percent.

F-76 pour point increases 6.3 percent.*

Table 17. Navy fuel marginal cost changes during production of 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines (cost changes relative to marginal costs during production of 100 percent conventional gasoline with 9.7 RVP)

Region	Marginal cost change (cents/gal)	
	JP-5	F-76
BOMs 1 & 2	NA	-0.2
BOMs 7 & 11	-0.8	NA
BOM 8	-5.2	-5.0
BOMs 9 & 10	-4.0	-2.8
BOM 13	-0.2	0.0

*The report on *Navy Fuel Production in the Year 2000*[17] suggests that, *compared to the year 1990*, the production costs of Navy fuel will increase for business-as-usual conditions in the year 2000. An important component of the cost increase between 1990 and 2000 is the increased costs of crude oils. That report also suggests that domestically produced JP-5 and F-76 will have increased aromatics contents, *the result of an assumption which limits the aromatics content of highway diesel fuel to 20 maximum volume percent.*

4. OVERVIEW OF FUEL PRODUCTION IN THE YEAR 2000

Seventy-five percent of the nation's total crude oil distillation capacity is located in the coastal and near-coastal study regions of BOMs 1, 2, 7, 8, 9, 10, 11, and 13.[18-20] Compared to the base case for production of 9.7 psi RVP conventional gasoline, the forecasting system suggests that the regional reformulation costs for producing 7.0 psi RVP RFG could be 3.5 to 5.6 cents per gallon in the year 2000, as shown in Figure 2.

The reformulation costs are sensitive to assumptions about the relative value of MTBE. In this study, MTBE is valued 28.1 cents per gallon above conventional gasoline.

The MTBE contribution to the reformulation cost is about 3.2 cents per gallon, and increased refining costs add between 0.3 and 2.4 cents per gallon to the reformulation cost.

The reformulation costs (between 3.5 and 5.6 cents per gallon) do not account for blendstock effects on gasoline heating value. For heating value equivalent to one gallon of conventional gasoline, the regional total added costs (including reformulation costs) for RFG could be 5.9 to 8.0 cents, as shown in Figure 3.

In blending RFGs, the reduction of butane for lower RVP and the reduction of reformate for lower aromatics are generally compensated by increased percentages of alkylate and/or straight run naphthas.

Table 18 compares the additional process capacity in the study regions for producing 50:50 conventional (8.7 psi RVP) and reformulated (7.0 psi RVP) gasolines relative to the process capacity for production of 100 percent conventional gasoline with 9.7 psi RVP. Both production schemes include civilian highway diesel fuel restricted to 0.05 weight percent maximum sulfur and a minimum cetane index of 40.

Larger capacity additions are required for butane isomerization, alkylation, aromatics recovery, and distillate hydrotreating. Compared to current capacity:

Butane isomerization capacity increases by 196 percent.

Alkylation capacity increases by 11 percent.

Aromatics recovery capacity increases by 36 percent.

Distillate hydrotreating capacity increases by 2 percent.

Other capacity additions are either less than 1 percent of current capacity or have no current capacity for comparison.

Utilization of crude distillation capacity is about the same in the cases for production of RFGs as in the base case production of conventional gasoline. Total product output is increased by approximately the amount of oxygenate purchased for RFGs. However, the purchased oxygenate

Figure 2
Gasoline reformulation costs in the year 2000
(7.0 psi RVP)

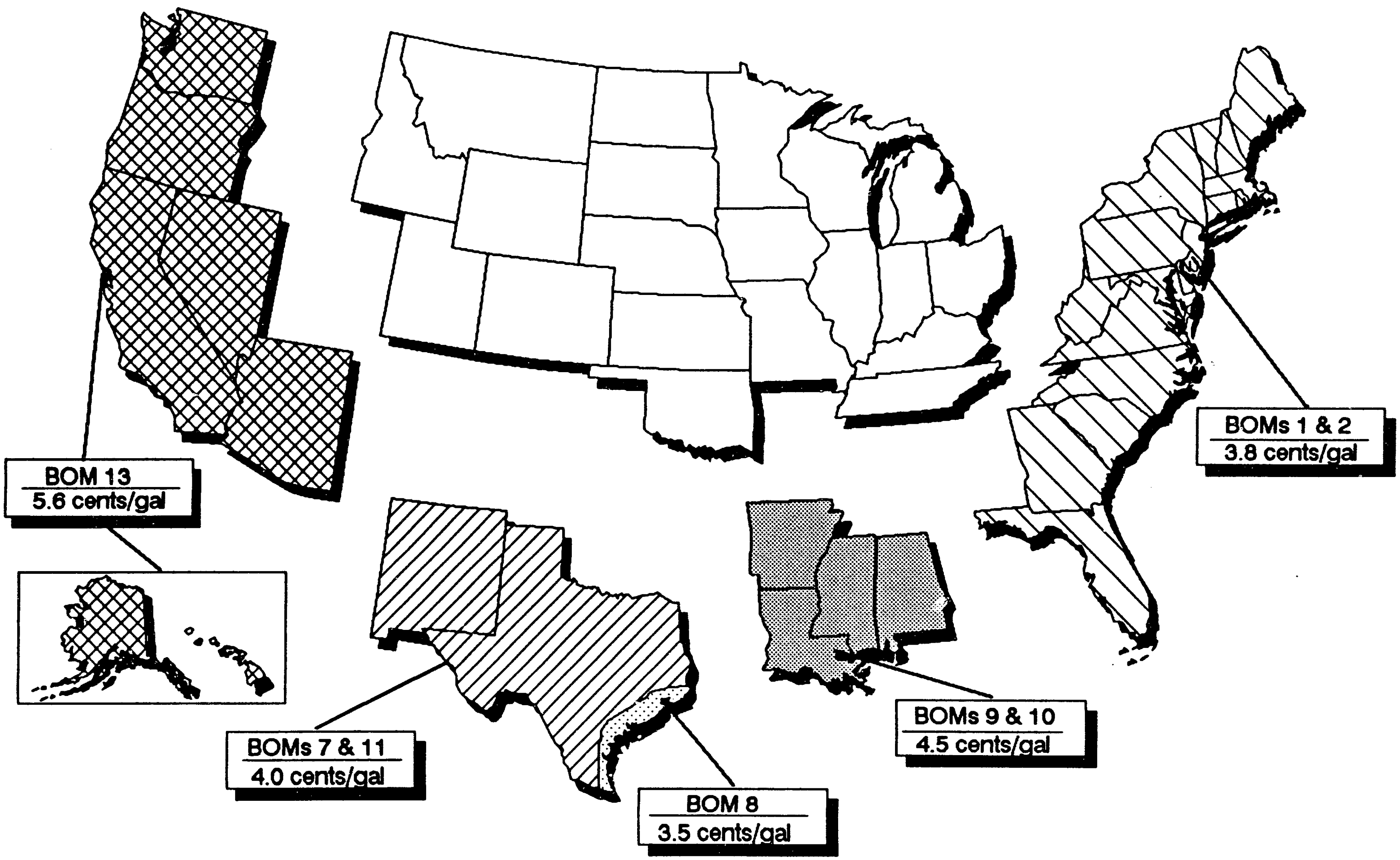
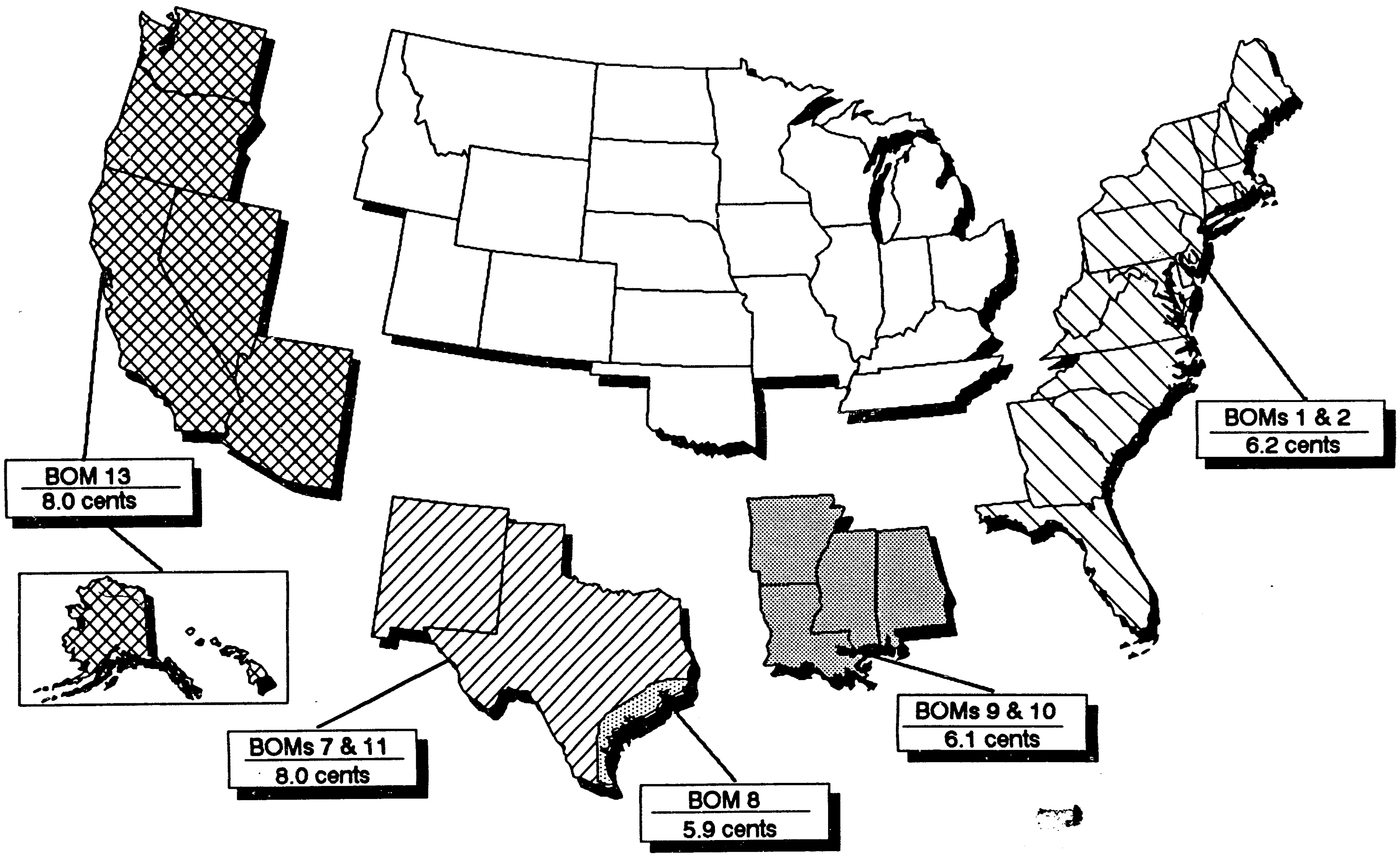


Figure 3
Added costs for reformulated gasoline with heating value equivalent to one gallon of conventional gasoline



eases the competition for blendstocks and reduces the marginal cost of production of certain fuels. For example, the marginal costs of production of Navy fuels decrease by as much as 5.2 cents per gallon during production of 7.0 psi RFG.

To satisfy the anti-dumping provisions of the CAA, the quality of conventional gasolines does not deteriorate in the cases which also include production of RFGs. Gasoline reformulation has little effect on the quality of Navy fuels except for BOMs 9 & 10, in which there are degradations in the aromatics content and smoke point of JP-5 and in the pour point of F-76.

Table 18. Capacity additions to produce 50:50 conventional (8.7 RVP) and reformulated (7.0 RVP) gasolines in the study regions (compared to capacity for production of 100 percent conventional gasoline with 9.7 RVP)

Process	Capacity (MBD)
Alkylation	83.8
Butane isomerization	106.6
C3/C4 dehydrogenation	6.0
Aromatics recovery	71.3
Distillate hydrotreating	44.3
Visbreaking	4.3
FCC feed hydrotreating	1.3
Solvent deasphalting	9.2
Hydrogen production	0.8
MTBE	1.0

5. CONCLUSIONS AND RECOMMENDATIONS

The preliminary assessment of the future refining impacts of the CAA suggests that in domestic coastal and near-coastal refining regions:

- The cost of gasoline reformulation in the year 2000 could be 3.5 to 5.6 cents per gallon (in terms of 1989 currency). For heating value equivalent to one gallon of conventional gasoline, the regional total added costs (including reformulation cost) for RFG could be 5.9 to 8.0 cents.

- In blending RFGs, the reduction of butane for lower RVP and the reduction of reformate for lower aromatics are generally compensated by increased percentages of alkylate and/or straight run naphthas.

- Relatively larger refinery process capacity additions are required for butane isomerization, alkylation, aromatics recovery, and distillate hydrotreating.

The relative value of MTBE appears to be the most important determinant of the cost of reformulation. *MTBE cost sensitivity analysis is recommended for future studies of gasoline reformulation costs.*

The preliminary assessment focused on the effects of changes in RVP, oxygen content, aromatics content, and benzene content of gasoline. In the year 2000, vehicular emissions of volatile organic compounds, nitrogen oxides, and toxic compounds will be determined by statistically estimated models which will probably include the effects of oxygen content, aromatics content, sulfur content, olefins content, and the 90 percent distillation temperature of gasoline. *It is recommended that future studies of reformulation describe gasolines in terms of all independent variables expected to be in the emission performance models of the year 2000.*

The regional refinery models used in the preliminary assessment assume that all refineries within a large region are interconnected. Consequently, the models have a tendency to over-optimize refinery operations. It has been demonstrated that disaggregation of refinery complexity classes reveals important differences in product producibility and process requirements which go undetected at the aggregate level.[21] A major difficulty with disaggregation is the limited availability of data on raw material inputs and product outputs for different refinery complexity classes. *It is recommended that, to the extent permitted by data availability, refinery complexity class disaggregation should be a feature of future studies of gasoline reformulation.*

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