A SUMMARY AND EVALUATION OF EXISTING ECONOMIC MODELS OF THE PETROLEUM REFINING INDUSTRY

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ABSTRACT

The California Air Resources Board is attempting to improve its in-house capability to evaluate cost analyses of candidate control measures and proposals related to changes in pollutant emissions from petroleum refineries in California. To improve its capability, the ARB is seeking a long-term economic model of the California petroleum refining industry which incorporates consumer and producer impacts.

This report provides a descriptive and critical review of currently available models which may be adaptable to the petroleum refining industry. Included are a detailed description of relevant models, an assessment and discussion of the relative merits and weaknesses of the various models, and a description of possible adaptation and development procedures.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

A. Statement of the Problem

The California Air Resources Board (ARB) is attempting to evaluate the impact of air quality regulations on California industry. A careful evaluation needs to include:

<u>Estimates of the Discharge of Deleterious Substances</u>. Policymaking must start with "baseline" estimates of emissions. However, "emissions" includes a wide variety of substances. While the ones of primary interest in this study may be SOx and NOx, the production of hydrocarbons, lead, solid wastes and thermal pollution, among others, must also be considered.

<u>Identification of the Many Alternative Modification Processes and Their Interrelation</u>. Once "baseline" emission levels have been calculated, options for changing the baseline may be considered. There are many options available for pollution disposition. Pollutants may be transformed, through techniques such as end-of-pipe treatment, changes in the production process, add-on treatment methods, revised product quality requirements, byproduct recovery and recirculation of residuals. They may also be emitted to a variety of media (air, water, landfill). Often, the various pollutants and discharge media are treated separately. Yet a decrease in emissions of one pollutant or reduction in the use of a particular disposal medium usually implies that more of another pollutant is emitted or heavier use is made of an alternative disposal option.

<u>Evaluation of the Costs Associated with Each Technique</u>. Pollution reduction costs can take several forms, many of which are neither obvious nor monetary. Changes in costs to producers and consumers are only some of the impacts; changes in the product mix and local impacts upon employment and income must also be considered. Often, there is little information on what the various techniques cost and how producers and consumers will respond to new regulations. Yet without information on alternative options it is extremely difficult to implement pollution control regulations because threats of industry shutdowns or significant cost increases will split opinion.

Petroleum refining is one of the industries the ARB is analyzing, for a number of reasons. Refineries are an important source of production, employment, income and revenue in California. In 1984, nearly 20% of the operable refineries in the United States were located in California.1/ In that year, refineries in Petroleum Administration for Defense (PAD) District V (which includes the states of Alaska, Arizona, Hawaii, Nevada, Oregon and Washington as well as California) produced more than 15% of the motor gasoline produced in the U.S., and represented nearly 17% of all U.S. refinery production.2/

However, petroleum refineries are also major stationary sources of pollution, particularly NOx and SOx. For example, a study of pollution transport using 1977 data and a 50 x 50 mile grid within the South Coast Air Basin noted that petroleum refining and production accounted for 14% of total and 16% of stationary source sulfur oxide emissions.3/ This is not the whole story, since "Virtually all of the sulfur entering the air basin ... arrived in a barrel of crude oil."4/ When refiners select crude oil quality and output mix, they make indirect decisions about the quantity and types of emissions. Refiners can also have direct effects, through techniques such as desulfurization operations; yet additional desulfurization, like other pollution control options, can increase costs for producers and consumers of the product.

Another reason for focusing upon the petroleum refinery industry is the potential availability of information for evaluating changes in pollution control policies. There is a relatively large amount of publicly available technical and cost data on refinery processes and refinery pollution control techniques. Futhermore, a number of models developed in the last twenty years have been exercised on petroleum refineries. Some of these models have been used by the industry itself, to improve refinery operations and to anticipate future capacity needs; other models have been developed to assess national energy and environmental issues.

If existing petroleum refining models and data are applicable to pollution control issues in the state of California, they can greatly assist the ARB in its evaluation of the effects of air quality regulations on California industry. This report summarizes the existing models, and evaluates their use to the ARB.

As noted above, an economic evaluation of the alternatives for controlling refinery emissions would require information on:

(1) emissions levels,

(2) how pollution control regulations affect refinery production decisions, and

(3) how changes in refinery production affect product prices, sales, and other economic variables.

There is not now a California-specific model which can generate information on the latter two issues. However, there are a number of national and regional models which may be applicable. While the emphasis of many of these models has been upon energy policy, environmental attributes have been (or could be) included.

The problem now is to determine which (if any) of the existing petroleum refining and production models are applicable to the ARB need for an in-house capability to evaluate alternative pollution control options.

To address the problem, this report:

- identifies available modeling resources,
- presents the strengths and weaknesses of each model, and
- indicates how each model may be used by the ARB to meet its regulatory needs.

B. Objectives of the Study

The specific research objectives of this project were to:

(1) acquire literature on existing petroleum refining models;

(2) analyze existing models;

(3) indicate how the models meet ARB policy-making needs;

(4) identify modifications/steps necessary for the ARB to obtain a petroleum refining model which satisfies ARB needs; and

(5) document these results.

C. Approach

To accomplish the research objectives, tasks reflecting each objective were defined and completed. Each task is described below.

1. Task 1: Literature Search and Acquisition of Documentation

For the first task, existing models were identified and the availability of documentation was assessed. Both published sources and personal contacts were used to develop a list of models pertaining to the petroleum industry and to petroleum refining.

2. Task 2: Description and Analysis of Existing Models

Existing models vary tremendously in their purpose, coverage, and degree of detail. In Task 2, detailed information on each available model was acquired. General characteristics of the model, as well as specific information on equations and data requirements, were provided.

3. Task 3: Criteria Development

Which model will be most "appropriate" depends upon the purpose for which it will be used. In Task 3 the criteria for choosing among the models identified in the previous two tasks were specified. A set of possible criteria were developed and submitted to Air Resources Board personnel for discussion, prioritization, and approval.

4. Task 4: Recommendations

Recommendations obviously depended upon the results obtained in previous tasks. If usable model(s) were found, the necessary modifications and resource requirements (e.g., time, effort, money, data development, software requirements, computer capacity) were to be indicated. If no suitable models were found, the steps necessary to develop such models, and the appropriate resource requirements, were to be outlined.

5. Task 5: Final Report

A draft report reflecting the results of Tasks 1-4 was developed. After review of the draft by the Air Resources Board, a final report incorporating review comments was prepared.

D. Overview of the Report

Chapter II describes the literature search. The search included both a formal search of published sources and telephone conversations with organizations and individuals who may have been involved in relevant research. Listings obtained through the formal literature review are summarized in Part I of Appendix A. Summaries of the individuals and institutions engaged in economic and petroleum refinery modeling are included in Appendix B. The summaries contain the name of the organization, its location (city and state), and a brief history of its experience (models and applications) in the area.

The material in Chapters III-V of this report follows a "two-tiered" format. First, a brief description of models which are potentially applicable is given in Chapter III. After the criteria for choosing among models are enumerated in Chapter IV, those models which still appear to be applicable are discussed in more detail in Chapter V. Conclusions and recommendations appear in Chapter VI.

FOOTNOTES TO CHAPTER I

1. California had 39 of the 214 operating refineries, and 43 of the 247 total refineries. See U.S. Energy Information Administration, Petroleum Supply Annual: 1983. (Washington, DC: U.S. Government Printing Office, June 1984), Refinery Table 1.

2. See Table 5 of Petroleum Supply Annual, op. cit. The data is based upon Petroleum Administration for Defense (PAD) Districts. California is in PAD District V, along with the states of Washington, Oregon, Nevada, Arizona, Alaska, and Hawaii. The other PAD V states have 14 operating refineries.

3. Total sulfur oxides emissions within the 50 by 50 mile grid (in short tons per day of SO_2) were 429 tons. The petroleum refining and production industry contributed 60 tons, while all stationary sources accounted for 371 tons. For more information, see Table 1a in Glen R. Cass, Robert W. Hahn and Roger G. Noll, Implementing Tradable Emissions Permits for Sulfur Oxides Emissions in the South Coast Air Basin, Final Report, Volume II (Pasadena, CA: Caltech Environmental Quality Laboratory, June 30, 1982).

4. Cass, et al., op. cit., Volume II, p. 46.

II. EXISTING LITERATURE

Published sources and personal contacts were used to develop a list of models pertaining to the petroleum industry and petroleum refining. Over a hundred articles, papers, books and other documents were identified in the search process. Many of these documents were not applicable to the current study, and were eliminated after reviewing the document abstract or the document itself. A formal search of published literature was completed first; references in these documents, and personal contacts with individuals and organizations having some experience in the field, supplemented the original number of listings.

A. The Search Process

The formal literature search used the computer-based library capabilities of the Dialog Information Services system (or "Dialog"), which is a subsidiary of Lockheed Corporation. Dialog is the largest database collection currently available. It offers access to over 200 databases, and the present collection contains over 100 million records; these records include every book in the Library of Congress, and citations to articles in 10,000 different journals. Within the Dialog system, entries were pulled from several different databases, including the National Technical Information Service (NTIS), Department of Energy (DOE) Energy Database, Energyline, and Compendex. Several other databases were also examined, but did not include relevant material. The "search strategy" (the order in which keywords are included so the search is limited to applicable documents) can influence the number of documents cited. Thus, several search strategies were utilized to obtain the references.

The Dialog search identified 104 documents to be considered. An initial screening of the 104 document abstracts indicated that many would not be of further relevance to the present study. Some of the articles merely described new petroleum refinery technologies; several of the listings were only available in a foreign language (9 were in Russian); a few documents appeared in more than one database, or were separate references to individual volumes in a multi-volume report; two listings in a "Work in Progress" database were halted before the modeling effort was complete. The initial screening of abstracts eliminated 39 listings from further analysis. (A summary of the initial screening is shown in the first part of Table II-1).

The remaining 65 documents were ordered, received, and reviewed. During this second "screening," additional documents were found to be inapplicable. Some were brief news reports or simple technology descriptions; in one case the "refinery industry model" that was described was developed for the aluminum refining industry. As shown in Table II-1, this second screening further reduced the number of relevant documents to 39 listings. These listings are summarized in Part I of Appendix A.

TABLE II-1. PUBLISHED INFORMATION ON ECONOMIC MODELS OF PETROLEUM REFINING

I.	Documents identified through formal literature search		104
	A. First screening (of abstracts) eliminated 39 documents:		
	1. Technology descriptions	15	
	2. Foreign language only	10	
	3. Duplicate listings	12	
	4. Research halted	2	39
			65
	B. Second screening (of documents) eliminated 26 more listings:		26
			39
II.	Documents identified through citations and personal contacts		21
	TOTAL DOCUMENTS LISTED IN APPENDIX A		60

The listings shown in Part I of Appendix A indicate some of the difficulties associated with reliance upon published sources:

- Many sources are out-of-date. This is particularly true for information on sponsors: the Department of Energy (DOE) is constantly being reorganized; the Texas Energy and Natural Resources Advisory Council (TENRAC) has disbanded; the NSF Research Applied to National Needs (RANN) Program no longer exists. Tracking down further information on models developed by these organizations can be very difficult.

- Knowledgable individuals have moved elsewhere. For example, much work in this area was done at the University of Texas; James Calloway is no longer there, and Russell Thompson operates primarily through a private company (OPCON). The individuals in charge of energy research at the National Science Foundation are now housed in the Division of Policy Research and Analysis and the Economics Division. Thus, even if an organization still exists, the individuals most familiar with the research, assumptions, and models may not be present.

- Important models are not included. For example, the Department of Energy has recently completed a model of U.S. petroleum refining (REMS). Because of cataloging lags and omissions of working papers, much literature could be missed unless other approaches are used to obtain information on current research in the area.

Thus, the formal literature search was supplemented in several ways. The articles cited in the formal search, and the references appended to each article, provided an initial list of organizations and individuals to contact. The Principal Investigator was also familiar with many individuals involved in this area of research, and included these in the list of personal contacts.

The list of organizations which were contacted is shown in Table II-2. The list is a mixture of sponsors and grantees. For example, the Electric Power Research Institute sponsored much of the work at the Energy Modeling Forum, and Oak Ridge National Laboratory work was funded by the Department of Energy. This "repeat questioning" reduces the probability of missing any existing work that may be applicable to the study.

Through personal contacts and references cited in previously acquired documents, an additional 21 listings were added to the 39 documents already under consideration via the literature search. The additional 21 listings are summarized in Part II of Appendix A.

B. Families of Literature

The sixty references cited in Appendix A are not all independent studies of the refining industry. Many of the documents can be grouped together by performing organization, by a source of funds, or by interactions among individuals (e.g., a thesis advisor and student). Before continuing on to analyze distinct models, it will be useful to see how many "family trees" are involved. The geneaology is illustrated in Table II-3.

TABLE II-2. LIST OF ORGANIZATIONS CONTACTED

In Washington DC:

American Petroleum Institute (API)

Department of Energy (DOE)

- Economic Regulatory Administration. Office of Special Counsel (OSC)
- Energy Information Administration (EIA)

Department of Transportation (DOT). Office of the Assistant Secretary for Policy, Plans, and International Affairs (OASPPI)

Environmental Protection Agency (EPA)

National Aeronautics and Space Administration (NASA)

National Oceanic and Atmospheric Administration (NOAA)

National Petroleum Refiners Association (NPRA)

National Science Foundation (NSF)

- Division of Policy Research and Analysis (PRA)
- Division of Social and Economic Science (SES)

Resources for the Future (RfF)

Sobotka and Company, Inc.

In California:

California Energy Commission (CEC)

Electric Power Research Institute (EPRI)

Energy Modelling Forum (EMF)

Environmental Quality Laboratory (EQL)

Lawrence Berkeley Laboratory (LBL)

Robert Brown Associates

Southern California Edison (SCE)

Systems Science and Software (S3)

TABLE II-2. LIST OF ORGANIZATIONS CONTACTED
(cont'd)

Maryland:

Department of Economic and Community Development

Massachusetts:

Arthur D. Little, Inc. (ADL)
Data Resources, Inc. (DRI)

New Jersey:

MathTech

Rhode Island:

University of Rhode Island

Missouri:

University of Missouri - Rolla/Department of Natural Resources (UMR-DNR)

Tennessee:

Oak Ridge National Laboratory (ORNL)

Texas:

Bonner and Moore Associates, Inc.
OPCON
PACE Company Consultants and Engineers
Texas Air Control Board
Texas Public Utilities Commission
Turner Mason Associates
University of Houston
University of Texas at Austin

Washington:

Pacific Northwest Regional Commission

Other:

International Institute for Applied Systems Analysis (IIASA)

University of London

TABLE II-3. FAMILIES OF DOCUMENTS

<u>Resources for the Future</u>

Howe <u>et</u> <u>al</u>. (1971)
Russell (1973)

Rice (1976)
Rice and Smith (1977)

<u>The University of Houston</u>

Calloway <u>et</u> <u>al</u>. (1976)
Thompson <u>et</u> <u>al</u>. (1976)
Thompson <u>et</u> <u>al</u>. (1978)

<u>Texas Energy and Natural Resources Advisory Council (TENRAC)</u>

Center for Energy Studies, University of Texas at Austin:
- Kendrick <u>et</u> <u>al</u>. (1981)
- Suh (1982)
- Langston (1983a)
- Langston (1983b)

Texas Air Control Board:
- Texas Mid Continent Oil and Gas Association (1974)
- Stewart (1975)

<u>Arthur D. Little, Inc.</u>

Godley <u>et</u> <u>al</u>. (1976a)
Godley <u>et</u> <u>al</u>. (1976b)
Godley <u>et</u> <u>al</u>. (1976c)
Kittrell <u>et</u> <u>al</u>. (1976a)
Kittrell <u>et</u> <u>al</u>. (1976b)

<u>Bonner and Moore</u>

Bonner and Moore Associates, Inc. (1974)
Bonner and Moore Management Science, Inc. (1983)
Bonner and Moore Management Science, Inc. (no date)
Bryant (1981)
Dickson <u>et</u> <u>al</u>. (1982)
Dickson <u>et</u> <u>al</u>. (1983)
Moore (1983)
Tukenmez <u>et</u> <u>al</u>. (1978)

TABLE II-3. FAMILIES OF DOCUMENTS
(continued)

Turner Mason Associates

McGregor (1980)

The Pace Company Consultants and Engineers

The Pace Company Consultants and Engineers (1974)
McGregor (1980)

Other Proprietary LP Models

Jones *et al*. (1981) -- Gulf
Hoot (1974) -- M. W. Kellogg
O'Hara *et al*. (1981) -- Parsons

The Department of Energy -- REMS

The Department of Energy, Energy Information Administration (1984a)
The Department of Energy, Energy Information Administration (1984b)

U.S. Environmental Protection Agency (1984)
Schwartz *et al*. (1984)

Econometric Modeling Efforts

Ford Foundation/DRI/Harvard:
- Data Resources, Inc. (1984)
- Hudson and Jorgenson (1976)
- Kennedy (1976)
- Verleger and Sheehan (1976)

Wharton/Penn:
- Griffin (1972)
- Adams and Griffin (1975)

Others:
- Chou (1977)
- Lakhani (1975)
- Pagoulatos (1977)
- Rollins (1978)
- Wilkins (1978)
- Wilkinson (1974)

TABLE II-3. FAMILIES OF DOCUMENTS (continued)

EPRI/EMF

Sweeney (1979)
Sweeney (1983)

International Models

Babusiaux and Valais (1980)
Babusiaux *et al*. (1983)
Deam *et al*. (1973)

Readings/Discussions/Comparisons

Linear Programming:
- Lasdon and Waren (1980)
- Levine (1974)
- McCall (1974)
- Michalski (1983)

Model Comparisons (International):
- Beaujean (1978)

Petroleum Industry, Petroleum Refining:
- Banks (1983)
- Jacoby (1978)
- Niemeyer (1978)

Pollution Control, Regulations:
- Conser (1972)
- Gamse and Speyer (1974)

Some of the earliest policy studies of petroleum refining were undertaken at Resources for the Future (RfF). The National Water Commission asked RfF to evaluate future water supply and demand patterns. As part of the study, three industries were analyzed in detail: thermal electric power, beet sugar refining, and petroleum refining. The water study was summarized in Howe (1971), and work with the petroleum refining model was continued by Russell (1973). In a separate effort, another RfF employee -- V. Kerry Smith -- would serve as a thesis advisor for Patricia Rice. This collaboration resulted in a dissertation and a journal article which used the petroleum refining industry as a case study.

The Russell model of petroleum refining was updated and used in a multi-year study conducted at the University of Houston. The university received a large Research Applied to National Needs (RANN) grant from the National Science Foundation to evaluate the costs heavy industry would incur in meeting the guidelines of the 1972 Water Law (P.L. 92-500). RANN funding allowed the university to build a set of integrated industry models of the U.S. economy. Versions of these models are kept current and used by Dr. Russell Thompson, who was a Principal Investigator in the RANN study and is now president of a small operations research firm (OPCON) in the Houston area.

The RANN program also funded a number of other efforts. One was co-funded with the Texas Governor's Energy Advisory Council, later known as the Texas Energy and Natural Resources Advisory Council (TENRAC). Since Texas was a major producer of refined petroleum products, energy and environmental legislation would have profound implications for the Texas economy. A number of studies were commissioned by TENRAC at the Center for Energy Studies at the University of Texas at Austin. Efforts by Kendrick _et al_. (1981), Suh (1982), and Langston (1983a, 1983b) were some of the results in the area of petroleum refining. TENRAC funding was also used by the Texas Air Control Board, and produced two studies of relevance to the current project.

Another body of work was being funded by the Environmental Protection Agency (EPA) at approximately the same time. A large grant went to Arthur D. Little, Inc. to mathematically model the petroleum refinery industry and to predict the impacts of several pending and proposed policy changes regarding gasoline. Five studies were direct results of this effort. Furthermore, individuals associated with the ADL effort would move on to private modeling firms, and continue the development and spread of refining industry models.

Long before the public interest in petroleum refining models, private firms had been using linear programming (LP) models of refining plants to optimize process outputs and cost. Several proprietary models were developed and used repeatedly for energy decisions. Some of the more widely known LP firms include Bonner and Moore, Turner Mason and Associates, Pace Consultants, and Sobotka. Models developed by these firms have been used in a number of applications by public agencies as well as private companies; reports resulting from these applications are listed (by performing company) in Table II-3. An effort which was jointly funded by the National Aeronautics and Space Administration and the Department of Energy, looked at the refinery impacts of advanced energy sources. The refinery models available at Gulf -- Jones _et al_. (1981) -- and at Parsons -- O'Hara _et al_. (1981) -- were exercised in the NASA/DOE study.

The Department of Energy recently constructed a model of the petroleum refinery industry based upon the Turner-Mason and Bonner-Moore models: this model (REMS) has been used by DOE and by EPA. The four documents resulting from this effort are also listed in Table II-3.

Relatively large amounts of funding were also going to economic and econometric modeling efforts in the early 1970's. Table II-3 indicates two large families of econometric models that were being developed at the time. One family of models received its impetus from Ford Foundation Energy Policy Project money, and was closely associated with Data Resources, Inc., Harvard University and MIT. Another family of models used the Wharton forecasting model (rather than DRI) and was centered at the University of Pennsylvania. Both, incidentally, used versions of the Bonner and Moore refinery models in their studies. There were six other econometric studies of interest to the current research project, but they were only tangentially related to each other. For example, Wilkinson received advice from Adams on his dissertation, and both Chou and Kennedy used Takayama's spatial equilibrium model.

Two other relatively independent efforts are also included in the documents in Appendix A. One effort was funded by the Electric Power Research Institute, and carried out at the Energy Modeling Forum (EMF) at Stanford University. Two EMF documents by Sweeney are of interest. Another modeling effort was being undertaken internationally; three reports (Babusiaux and Valais, Babusiaux et al., and Deam et al.) are relevant from that literature.

Besides documents on specific models and their applications, Appendix A also contains a number of background documents relevant to the present study. Four papers describe progress and trends in the use of linear programming models for refinery management. Lasdon and Waren (1980) is a survey of uses of LP techniques, Michalski (1983) discusses some recent LP applications, Levine (1974) describes some new techniques that may be used in LP models, and McCall (1974) discusses the Exxon experience with LP models. Other topics included in the literature are descriptions of the refining process, comparisons of various energy models, and an overview of SOx emissions regulations and techniques.

C. Related Readings

This study covers a wide range of topics. Econometric modeling, petroleum refining technologies, statistical comparisons, linear programming techniques, and computer capabilities are just a few of the topics touched upon. Solutions to environmental issues must draw upon a number of technical and policy backgrounds, and no single individual is usually "fluent" in all the necessary concepts. Since the discussion which follows draws upon so many areas of study (and occasionally lapses into the jargon from those disciplines), this section provides a list of readings in the various topic areas which may be used by an interested reader who is unfamiliar with specific concepts.

Petroleum Refining. Refineries use an immense variety of equipment to process petroleum and remove unwanted residuals. An excellent overview of the kinds of processes used to refine petroleum and reduce emissions is contained in Chapters 3 and 4 of Russell (1973). A more detailed, although somewhat dated, description of the various options is available in Stephens and Spencer (1956).

Linear Programming. Refining is actually a composite of several different steps; which steps are used depends upon input costs and qualities, output prices, existing and expected regulations, and a host of other considerations. A mathematical technique which has been used to find the "best" solution to the many input, processing and technical considerations is known as linear programming. A definitive description of LP techniques is available in Gale (1960). Examples of LP applications to petroleum modeling and economic decision-making may be found in Lasdon and Waren (1980).

Statistical Concepts and Econometric Techniques. Comparisons among petroleum refining models will be based upon a number of measures of "accuracy" and "performance." (e.g., mean absolute percentage error, Theil's U, etc.). How the authors of various models handled the problems that appeared in the modeling process (e.g., autocorrelation, biased estimates) and the estimation techniques used (e.g., Ordinary Least Squares, Instrumental Variables, etc.) are also important considerations. Descriptions of the statistical concepts, and of the estimation techniques and problems, are contained in Theil (1978).

Computer Terms. The merits of a specific model are also dependent upon the computer hardware and software available to the user. Many of the models cannot be run on a small system (a "micro"), and all will require different amounts of calculation effort ("CPU time"), supporting equipment, and data. An excellent guide to the concepts associated with computer hardware and software is Sippl and Sippl (1980). Besides including a dictionary of computer terms and a glossary of acronyms, it also includes encyclopedia-like discussions of computer languages, data base management systems, operations research concepts, and a number of other pertinent issues.

D. The Next Step

Previous sections have identified sixty references of interest to this study, and have noted that the references are not all independent, but may be combined into "families" of literature. If the references are grouped into related modeling efforts, twenty-seven separate models can be identified. These models are listed in alphabetical order in Table II-4. Resources for the Future is responsible for two models: the RfF model, and the Rice/Smith model. TENRAC efforts also resulted in two models -- one by the University of Texas at Austin, and one by the Texas Air Control Board. Three other models can be derived from the listings on the first page of Table II-3: the University of Houston, Arthur D. Little, and Bonner and Moore models. The second page of Table II-3 contains five proprietary LP models -- Turner-Mason, Pace, Gulf, Kellogg and Parsons -- and a publicly available one (REMS). The Ford Foundation efforts resulted in four models of interest (DRI, Hudson/Jorgenson, Kennedy and Verleger/Sheehan) and the Wharton work produced one (Adams/Griffin). The other six econometric models (Chou, Lakhani, Pagoulatos, Rollins, Wilkins and Wilkinson) are each included separately. Work at Stanford produced one model of interest (Sweeney), and the international work has produced two (the French models, and the University of London model).

In the next chapter, these twenty-seven models are described in detail. The characteristics of interest to the Air Resources Board are summarized, so that comparisons among the models may be made in later chapters.

TABLE II-4. LIST OF CANDIDATE MODELS

The Adams/Griffin Model
The Arthur D. Little (ADL) Model
The Chou Model
The Data Resources, Incorporated (DRI) Model
The French Models

The Gulf Model
The Hudson/Jorgenson Model
The Kellogg Model
The Kennedy Model
The Lakhani Model

The Pace LP Modeling System (PMS)
The Pagoulatos Model
The Parsons Model
REMS -- The Refinery Evaluation Modeling System
RPMS -- The Refinery and Petrochemical Modeling System

The Resources for the Future (RfF) / Russell Model
The Rice/Smith Model
The Rollins Model
The Sweeney Model
Texas Air Control Board Model

The Turner-Mason-Solomon (TMS) Model
The University of Houston Model
The University of Texas at Austin Model
The University of London Model
The Verleger/Sheehan Model

The Wilkins Model
The Wilkinson Model

III. EXISTING MODELS OF PETROLEUM REFINING

This section of the report describes models which may be used to evaluate economic impacts of pollution regulations on the petroleum refining industry. Before going into detailed descriptions of pertinent models, however, it will be useful to indicate the alternative approaches for evaluating pollution impacts on an industry.

A. Alternative Approaches for Measuring Pollution Impacts

If the ARB is trying to determine how their decisions affect trends in industry and the California economy, there are a number of approaches which may be used. The two main alternatives are top-down (also known as "macro" models) and bottom-up, or "micro," options. Within each category, there are two possibilities; each of the four possible approaches is discussed below.

The two top-down approaches (also known as macro approaches) are input-output analyses and satellite models. Satellite models (also called spin-off, or generation coefficient models) are by far the easiest and cheapest to use. The generation of residuals is directly tied to particular industrial activities -- sales, employment, or some other input or output -- and predicted levels of pollution follow the patterns of industrial activity. The Texas Air Control Board used this approach when it tried to estimate the impact of various energy growth patterns on air quality in the state of Texas. Data on Texas refinery capacity, emissions, and fuel usage were available for 1972, and were used to develop baseline estimates of emissions which were directly tied to refinery capacity and fuel usage. Projections of future growth in capacity and changes in fuel mix and capacity utilization were made, based upon discussions with the various refiners and forecasts of regulatory restrictions. These capacity and fuel use projections were then compared with actual 1972 data to obtain emissions estimates for 1985 and 2000. The report by Stewart (1975) contains more information on the study.

The other top-down approach uses input-output (I-O, or interindustry) analysis to estimate how a change in output in any particular sector changes output in all other sectors. This I-O analysis requires information on transactions between every industry in the economy; all producing and consuming sectors must be included in the input-output database, even if several sectors have to be lumped together. Petroleum refining would be only one small portion of an I-O analysis. This interindustry transaction information is used to develop I-O coefficients, which indicate how an industry is affected by changes in another industry. If the I-O coefficients are assumed to be stable over time (a dubious assumption, as indicated below), then the coefficients can be used to determine how alternative policy decisions might affect various industries and sectors of the economy. An example of such an approach is provided by Wilkins (1978) in his study of the Pacific Northwest region (Washington, Oregon, and Idaho). Wilkins attempted to determine how energy policies affected regional production, employment, consumption, exports, and imports. Another example of the interindustry approach, as well as a brief overview of input-output analysis, is contained in Hudson and Jorgenson (1976).

The main problem with the two top-down techniques is that they must assume background factors do not change. Fixed coefficients -- whether they are for simple "scale up" models such as the one used by the Texas Air Control Board, or for large and complex input-output models -- cannot account for variations in future technical/environmental/economic conditions, nor are they flexible enough to allow for an array of policy options. But this is exactly the kind of information a public agency such as the ARB would be seeking. If top-down (or satellite, or macro, or interindustry, or I-O) analyses are not adequate for policy-making purposes, then the alternative options -- bottom-up, or "micro" models -- must be considered.

One of the "bottom-up" approaches is usually referred to as the "damage function" approach (terms such as "treatment cost functions" or "dose-response analyses" are also used). The damage function approach begins with emissions and air quality data, and traces through alternative policy options using damage functions and cost/benefit analysis. The other approach is often referred to as "process modeling;" it begins with models of particular industries, and appends air quality considerations to the production decisions.

The "damage function" option has been widely used. (See, for example, the work of Rowe (1985) on agricultural crops in the San Joaquin Valley). The models start with emissions inventories and meteorological information to estimate air quality levels. Air quality estimates are combined with damage functions, to indicate impacts on health, materials, crops, or other items. The economic benefits associated with improved air quality levels are compared to the costs of obtaining these improvements. Policy decisions can then be based upon the relative costs and benefits of alternative options.

However, "damage function" models do not explicitly include the possibility of production process changes. Such process changes -- changes in the production technology, input or output mix -- may have significant effects upon emissions output. Furthermore, process changes may also be the cheapest as well as the easiest response. For example, a study by Russell (1973) shows that pollution discharges vary substantially with processing options; for several residuals, the costs involved in obtaining particular discharge levels are lower when nontreatment alternatives are considered. Because treatment cost models do not explicitly include production, they cannot account for responses that are due to process changes. Since policy-makers are seeking the simplest and most cost-effective solutions to improved environmental quality, process alternatives should be included in any situation where such alternatives are likely to have a significant impact on the quantity and mix of emissions.

The other "bottom-up" option -- process modeling -- explicitly includes the technical and economic alternatives available to an industry. Detailed information on the inputs (quantities, types, costs and characteristics), processing technologies, and outputs (residuals as well as marketable products) must be acquired. A model of the process is developed, and used to determine optimal production levels, output mix, input combinations, and resulting residuals. One mathematical technique which has been used to find the "best" solution to the many input, processing and technical considerations in process models is known as linear programming, or LP. Because LP techniques are used so often in process models, "LP models" and "process models" are sometimes used as synonyms; however, "process modeling" is the more general term, with "LP model" referring to the subset of process models that use linear programming as the technique for finding an optimal solution. In any case, a process model allows for indirect influences -- changes in technology, product mix, quality specifications -- as well as the usual treatment options.

Which of the four approaches (top-down/IO, top-down/satellite, bottom-up/damage function, bottom-up/process modeling) is used in policy formulation depends upon the time and funds available, and the characteristics of the industry under study. If many of the important background conditions are likely to remain the same, all four approaches may be considered. Satellite models are easy to develop and relatively inexpensive to use. Input-output models are appropriate if a "broad brush" look at the entire economy is desired. However, if many of the important background conditions are likely to change, bottom-up models have a distinct advantage.

Both of the "bottom-up" approaches allow for variation in policies and background conditions, and are therefore better for longer-range regulatory purposes than "top down" approaches. Process models are more expensive to construct and update, but can include many more options for reducing emissions. Damage functions require less industry data, but are not able to trace the effects of production changes. Which of the alternative bottom-up options is chosen depends upon the characteristics of the industry under consideration. Industries such as agriculture and construction may not have many production alternatives, while some of the manufacturing processes may entail a welter of choices. This is part of the reason the ARB is interested in models of the petroleum refining industry; refining is a relatively complex process, and recent technology improvements in refining only add to the need for a model which can evaluate the many production alternatives and their implications for the development of reasonable air pollution control regulations.

The models of petroleum refining considered in this study are summarized in Tables III-1 through III-27. Some are small econometric models that were prepared as part of a Ph.D. dissertation; others are very large linear programming models that have been used many times by industry and government clients. Each entry in the tables presents the following information on a model: the name of the model; who built it (and why); a brief description of the model, including any subcomponents; examples of uses of the model; and references for further information.

Of the twenty-seven models listed, seven (DRI, Hudson/Jorgenson, Lakhani, Sweeney, the Texas Air Control Board model, Wilkins, and Wilkinson) use a "top down" approach. Hudson/Jorgenson (1976) and Wilkins (1978) use input-output analysis in their research. The other five are satellite models; estimates of the variables of interest are based upon industrial production, fuel economy, and other indices.

The next subsection uses economic concepts to group the approaches to petroleum refinery modeling. The basic characteristics of each model grouping are discussed, and examples of their use are given. After a brief discussion of the criteria which will be used to choose among the models (see Chapter IV), a more thorough discussion of the models relevant to this study is undertaken in Chapter V.

B. Economic Groupings of Models

Since the study emphasizes economic models of the petroleum refining industry, traditional economic terms can be used to classify the models. The models fall into three categories: supply-side models, demand-side models, and models which include both a demand and supply side. Supply-side models emphasize the production process and output decisions; demands for the products are taken as given, and producers attempt to meet product demands at the lowest possible cost. Alternatively, demand-side models focus on consumer choice. Consumers take the menu of goods available as given, and attempt to allocate their resources and choose a bundle of goods so they get the "most for their money." In reality, these production and consumption decisions are made simultaneously; thus, supply-and-demand models are the most comprehensive.

1. Supply-side Models

Models of refinery supply conditions are by far the most widely-used models in the literature. These models almost always include linear programming (LP) techniques to solve the model.

LP models are a linear function of variables the decision-maker wishes to optimize (either maximize or minimize), subject to a number of linear constraints involving these variables. The constraints usually fall into five classes: (1) raw material constraints (e.g., on the several types of crude oil supplied to the refinery), (2) refinery process utilization constraints, (3) production and distribution of final product constraints, (4) distribution and regional demand constraints, and (5) non-negativity constraints on all variables. The model calculates an optimum use of petroleum inputs, an optimum production of petroleum products, and an optimum distribution of these products across regions.

Examples of LP model applications are numerous. The most widely used LP models are those of Bonner & Moore Management Associates and Turner Mason Associates. The LP models of these two private firms have been used most often by refinery companies to optimize production and capacity utilization. The models have also been used by public agencies such as the Department of Energy for policy-making purposes. Examples of the policy use of such models are Dickson _et al_. (1982), Godley _et al_. (1976a and 1976b), Russell (1973), Schwartz (1984), and Tukenmez (1978). Of the twenty-seven models listed in Tables III-1 through III-27, twelve (A. D. Little, the French models, Gulf, Kellogg, Pace, Parsons, REMS, RPMS, Russell, the Texas Air Control Board model, Turner-Mason, and the University of London model) are supply-side models.

One of the main drawbacks of LP models is the lack of demand-side information; decisions are driven by technical factors rather than demand conditions. Because the quantity demanded is assumed rather than estimated, the reactions of consumers to changing product prices are not considered. This is not a particular problem when the model is set up to determine refinery output mix or capacity utilization, but is a problem when demand changes are one of the policy variables of interest.

2. Demand-side Models

A variety of studies have estimated the demand for refined petroleum products. The most widely studied product has been the demand for gasoline. Studies by Adams and Griffin (1975), Data Resources, Inc. (1984), Sweeney (1979), and Verleger and Sheehan (1976) estimated demands for gasoline. The studies by Adams and Griffin (1975) and DRI (1984) include petroleum products other than gasoline. Of the twenty-seven models listed in Tables III-1 through

III-27, four (DRI, Lakhani, Sweeney, and Verleger and Sheehan) are demand-only models.

Most of these models distinguish between short- and long-run demands. In the short run, demand is determined by the usage of petroleum-consuming equipment (such as automobiles and airplanes), whereas long-run demand is also affected by changes in the stock of equipment. Thus, short-run demand has much less flexibility than long-run demand; individuals are only able to change their usage patterns in the near future, but can seek out and purchase more efficient equipment as the time horizon increases.

Demand-only models cannot include producer decisions, or the technical information upon which those decisions are based. While the effects of policy changes upon consumer behavior can be analyzed, the influences of policy upon production or upon the interaction between consumption and production cannot be addressed.

3. Supply and Demand Models

A relatively recent group of studies have included both supply and demand considerations in their models. Eleven of the twenty-seven models in Tables III-1 through III-27 (Adams/Griffin, Chou, Hudson/Jorgenson, Kennedy, Pagoulatos, Rice/Smith, Rollins, the University of Houston model, the University of Texas at Austin model, Wilkins, and Wilkinson) use some form of demand and supply in their analyses. The models developed by Chou (1976), Kennedy (1974), and Rice (1976) are examples of the range of modeling techniques which may be used to include both production and consumption behavior. Chou uses a quadratic programming approach. The Kennedy model combines a modified version of the Bonner & Moore LP approach with a dynamic flow-adjustment demand model. The Rice model simultaneously estimates a series of econometric equations.

The assumptions, detail, estimating techniques, and applications of these models vary significantly. Some do not include important environmental variables, or are extremely simple representations of the petroleum industry. Others are estimated using simple econometric techniques such as Ordinary Least Squares (OLS); if the assumptions behind the econometric techniques are not met, the resulting estimates of consumer and/or producer behavior may be biased or inefficient. More will be said about these problems in the next two chapters.

TABLE III-1. THE ADAMS/GRIFFIN MODEL

Authors: F. Gerard Adams, James M. Griffin
Background: Model was developed as part of Griffin's Ph.D. dissertation at the University of Pennsylvania.

Model Summary: An econometric-linear programming model of the petroleum industry. The Wharton Long Term Industry Model is used to determine the setting (such as product demands) in which the petroleum model operates. Product demands are used as constraints on the linear programming portion of the model (which is a variation of a 1967 version of the Bonner and Moore model). The objective function is set to minimize the cost of producing outputs, and results in estimates of required crude inputs, output mix, total operating costs, and capacity utilization.

Submodels: The model is recursive in structure, but includes a linear programming submodel and additional equations determining product demands, inventory adjustments, imports, and supply and price conditions.
Equations: Includes an LP model of dimension 227 X 334, 14 equations estimated by econometric techniques, and 7 identities.
Variables: 74 variables (44 exogenous, 30 endogenous).

Applications: Adams-Griffin model results are compared with those of the Wharton Model.

Time Coverage: 1955-68 (simulation), 1970-75 (forecasts).
Regions: Entire U.S.
Industries: Petroleum refining.

Acquisition Information: Results of model publicly available. Actual data and equations were originally developed by Bonner and Moore (supply information), and Wharton Economic Forecasters, Inc. (demand information), with modifications and system-closing equations provided by the authors. Thus, most information available through Bonner and Moore and Wharton, probably on an on-line basis.

Availability: --
Computer System/Language: --
Costs: --

References: Griffin (1972), and Adams and Griffin (1975).

TABLE III-2. THE ARTHUR D. LITTLE (ADL) MODEL

Authors: Arthur D. Little, Inc.
Background: A series of studies commissioned by the Environmental Protection Agency.

Model Summary: Six linear programming computer models were developed to simulate a variety of refinery plants. Aggregation of these individual plant models is used as a representation of the petroleum refining industry as a whole.

Submodels: Six linear programming submodels (one for each grouping of refineries and/or regions with similar characteristics), plus additional equations determining product demands, inventory adjustments, imports, and supply and price determination.
Equations: Includes LP models of unspecified dimension, plus equations to scale up results obtained in each cluster model.
Variables: NA

Applications: Used to evaluate impacts on the refining industry of three policy options: low-sulfur, unleaded motor gasoline; SOx emissions control; and control of lead additives in gasoline.

Time Coverage: 1973-1985.
Regions: PAD districts and the entire U.S.
Industries: Petroleum refining.

Acquisition Information:

Availability: Proprietary, although an on-line usage capability at ARB may be possible.
Computer System/Language: NA
Costs: Subject to negotiation.

References: Godley <u>et al</u>. (1976a, 1976b), and Kittrell <u>et al</u>. (1976).

TABLE III-3. THE CHOU MODEL

Authors: Win-Lin Chou

Background: Model developed as part of Ph.D. thesis at the University of Illinois at Urbana-Champaign.

Model Summary: An econometric model of petroleum refining which includes both supply and demand considerations. A set of linear demand equations is developed, and supply is expressed as a linear programming description of the refining process (the LP model is MUNDIAL, developed by the Petroleum Economics Office of the Ministry of Mines and Hydrocarbons in Venezuela). The spatial equilibrium model of Takayama and Judge (1971) is used as the underlying economic model to determine an optimal solution to the many supply and demand conditions.

Submodels: NA

Equations: Based upon an LP model of dimension 1800 X 2000, plus a number of equilibrium equations.

Variables: NA

Applications: Model solved for 1974 input data, and compared with actual 1974 information.

Time Coverage: 1974

Regions: Six refined product consumption regions (PAD Districts I, III, and V; Western Europe; Japan; and the Caribbean) and two supply regions (Venezuela and the Persian Gulf).

Industries: Petroleum production, refining, and transportation.

Acquisition Information:

Availability: Publicly available list of equations and data sources.

Computer System/Language: NA

Costs: NA

References: Chou (1977)

TABLE III-4. THE DATA RESOURCES, INCORPORATED (DRI) MODEL

Authors: Data Resources, Incorporated
Background: Company developed model.

Model Summary: A macroeconometric model of the United States, and of the energy sector.

Submodels: Modeling effort is organized by key energy market segments -- energy prices, energy supplies, residential energy demands, commercial energy demands, transportation energy demands, and electric utility generation and fuel requirements. Modeling system is composed of the Macroeconomic Model of the U.S. Economy, World Oil Model, Energy Core Model, Coal Supply and Distribution Model, and Drilling Model.
Equations: Documented in the reference listed below.
Variables: Documented in Exhibit 1 of the reference listed below.

Applications: Used as input to the Verleger/Sheehan model (also known as the HVS model). Also used widely in private industry, primarily for demand forecasts.

Time Coverage: 1975-75 (for Verleger/Sheehan); data and forecasts updated quarterly. Quarterly data.
Regions: Entire U.S., some Census and PAD regions.
Industries: Petroleum refining, other 2-digit SIC classifications.

Acquisition Information:

Availability: Proprietary; on-line access possible.
Computer System/Language: NA
Costs: Subject to negotiation with DRI.

References: Data Resources, Incorporated (1984).

TABLE III-5. THE FRENCH MODELS

Authors: D. Babusiaux, M. Valais, others
Background: Developed for the Institut Francais du Petrole (France)

Model Summary: A compilation of several dynamic linear programming models; an energy planning model coupled with refining and petrochemical models.

Submodels: NA
Equations: Includes material-balance equations, demand equations, and quality equations (legal and technical specifications for each product).
Variables: NA

Applications: None available.

Time Coverage: --
Regions: --
Industries: --

Acquisition Information: None available

Availability: --
Computer System/Language: --
Costs: --

References: D. Babusiaux *et al*. (1983), and D. Babusiaux and M. Valais (1980).

TABLE III-6. THE GULF MODEL

Authors: Gulf Research & Development Company
Background: Company-developed model.

Model Summary: Proprietary set of models that includes a process submodel of separate processing units, an investment/capacity submodel, and optimization methods. The processing submodel can include five crude oils simultaneously. Investments, yields, and stream qualities are represented by equations and correlations. The model calculates material and utility balances, manufacturing expenses, and required investments.

Submodels: NA
Equations: NA
Variables: NA

Applications: Used to develop cost estimates for producing low quality turbine fuels, as part of a multi-volume National Aeronautics and Space Administration (NASA) study.

Time Coverage: Specific to the time period of the study (early 1980's).
Regions: Entire U.S.
Industries: Petroleum refining.

Acquisition Information:

Availability: Proprietary.
Computer System/Language: NA
Costs: NA

References: Jones et al. (1981).

TABLE III-7. THE HUDSON/JORGENSON MODEL

Authors: Edward A. Hudson and Dale W. Jorgenson

Background: Originally sponsored by the Ford Foundation's Energy Policy Project, follow-on funding has come from the Federal Energy Administration and the Department of the Treasury.

Model Summary: An input-output (interindustry) model is combined with econometric analysis to evaluate the effects of economic policy on supply.

Submodels: An interindustry model, where the entire economy is broken into nine sectors; and a macro-econometric growth model, which integrates demand and supply conditions for the economy.

Equations: NA

Variables: Documented in reference listed below.

Applications: Estimates are made of U.S. energy consumption under a variety of policy options.

Time Coverage: 1970-2000, in 5-year increments.

Regions: Entire U.S.

Industries: All U.S. industry, divided into 9 categories (refining is one industry).

Acquisition Information:

Availability: Algorithms and data located at Data Resources, Inc., Lexington, Massachusetts.

Computer System/Language: Computational algorithm embodied in a set of FORTRAN programs residing in the Burroughs 7700 computer operated by DRI.

Costs: Subject to negotiation with DRI.

References: Hudson and Jorgenson (1976).

TABLE III-8. THE KELLOGG MODEL

Authors: The M. W. Kellogg Company
Background: A company developed model.

Model Summary: A single-plant linear programming model of a refinery. Incorporates technical information on crude desalting and fractionation, gasoline production and blending, other petroleum products, and waste production.

Submodels: NA
Equations: NA
Variables: Documented in reference listed below.

Applications: Used to estimate the effects of producing low-sulfur gasoline.

Time Coverage: 1975-1985 (forecasts).
Regions: The entire U.S., and the state of California.
Industries: Petroleum refining.

Acquisition Information:

Availability: Proprietary.
Computer System/Language: --
Costs: --

References: Hoot (1974).

TABLE III-9. THE KENNEDY MODEL

Authors: Michael Kennedy
Background: Model developed as part of Kennedy's doctoral dissertation at Harvard University.

Model Summary: A world oil model, which is used to allocate regional refining capacity to meet regional demands at least cost. A linear programming model of the refinery decision process was developed by Bonner and Moore for this project. The outputs from the LP model are used in a spatial equilibrium model along with a series of demand conditions to determine the optimal solution to the many supply and demand constraints.

Submodels: The model has four segments: crude production, transportation, refining and consumption of products.
Equations: Linear programming model is of dimension 57 X 173.
Variables: Documented in reference listed below.

Applications:

Time Coverage: 1980.
Regions: Six -- besides the U.S., the model included Canada, Latin America, Europe, Asia, and the Middle East/Africa.
Industries: Petroleum production, transportation, and refining.

Acquisition Information:

Availability: Algorithms and data located at Data Resources, Inc., Lexington, Massachusetts.
Computer System/Language: Computational algorithm embodied in a set of FORTRAN programs residing in the Burroughs 7700 computer operated by DRI.
Costs: Subject to negotiation with DRI.

References: Kennedy (1976).

TABLE III-10. THE LAKHANI MODEL

Authors: Hyder Lakhani
Background: Model developed for Ph.D. dissertation at the University of Maryland.

Model Summary: Focuses upon the adjustment process to new innovations in refining technology. Uses regression analysis to estimate an S-shaped "growth curve."

Submodels: NA
Equations: Single equation representing diffusion of technology.
Variables: Growth rate in adoption of new refining technologies.

Applications: Uses empirical evidence to model the adoption of various cracking techniques (thermal to catalytic to hydro cracking). Estimates the benefits of increasing this diffusion rate.

Time Coverage: 1949-63.
Regions: The 18 states with the largest number of refineries.
Industries: Petroleum refining.

Acquisition Information:

Availability: Publicly available list of equations and data sources.
Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).
Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running a regression model.

References: Lakhani (1975).

TABLE III-11. THE PACE LP MODELING SYSTEM (PMS)

Authors: The Pace Company Consultants and Engineers, Inc.
Background: Company developed model.

Model Summary: A database and series of models on the refining industry. Much of the modeling capability is in single-plant refinery processes. Demand, price and import estimates are obtained from subscription to a commerially available economic forecasting service.

Submodels: Once information is obtained from the econometric model to which Pace subscribes, it is used in the Petrochemical Demand Model and Sector Demand Model. These demand estimates are used in the Energy Model, of which the Refinery LP Model is a subset. There is also a Pricing Model, which uses information from all of the previous submodels.
Equations: NA
Variables: NA

Applications: Used to evaluate the status and potential growth of the Texas petrochemical industry, and to corroborate a model used by DOE.

Time Coverage: 1972-82 (Texas); 1980 (DOE).
Regions: Texas for the 1972-82 study; the entire U.S. for DOE.
Industries: Petrochemicals for Texas; petroleum refining for DOE.

Acquisition Information:

Availability: Proprietary; will sell potential user the model.
Computer System/Language: PMS programs use the OMNI matrix generation language. Will run on a variety of mainframes (IBM, Univac, CDC, Amdahl), minicomputers (Prime, Vax, Data General), and a few microcomputers (Vax, Data General).
Costs: Installation will require the appropriate hardware, purchase of the PMS software, and acquisition of California-specific data. Costs for PMS will be subject to negotiation.

References: The Texas study appears in The Pace Company Consultants and Engineers, Inc. (1974). The DOE study is described in McGregor (1980).

TABLE III-12. THE PAGOULATOS MODEL

Authors: Angelos Pagoulatos, David Debertin and Emilio Pagoulatos
Background: --

Model Summary: Econometric model of petroleum exploration, extraction, and refining. Structural relationships were determined simultaneously.

Submodels: The model is block recursive with two blocks: one block estimates the supply and demand for refined products (using two-stage least squares) and the second block evaluates the discovery and extraction of crude oil (using three-stage least squares).
Equations: 37 stochastic equations, 3 identities.
Variables: 50 variables.

Applications: Used to analyze the effects of alternative pricing policies on U.S. domestic oil production, consumption and imports.

Time Coverage: 1959-76 (estimation), 1977-85 (prediction).
Regions: entire U.S.
Industries: Petroleum exploration, extraction, refining.

Acquisition Information:

Availability: Publicly available list of equations, variables and data sources.
Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).
Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running a simultaneous-equation model.

References: Pagoulatos (1977).

TABLE III-13. THE PARSONS MODEL

Authors: The Ralph M. Parsons Company
Background: Company-developed model.

Model Summary: Company developed, plant-specific linear programming model that determines optimum production from a given set of capital and operating costs, fuel characteristics, raw material feed costs, utilities, product slates and their market values.

Submodels: NA
Equations: NA
Variables: NA

Applications: Used to develop cost estimates for producing low quality turbine fuels, as part of a multi-volume National Aeronautics and Space Administration (NASA) study. Used two existing refineries (Mobil's Joliet, Illinois refinery and Marathon's complex at Robinson, Illinois) as typical examples.

Time Coverage: Specific to the time period of the study (early 1980's).
Regions: Entire U.S.
Industries: Petroleum refining.

Acquisition Information:

Availability: Proprietary.
Computer System/Language: NA
Costs: NA

References: O'Hara et al. (1981).

TABLE III-14. REMS -- THE REFINERY EVALUATION MODELING SYSTEM

Authors: U.S. Department of Energy, Energy Information Administration.
Background: Draws from third and fourth generation versions of the Turner-Mason and Bonner and Moore models. Current version was updated with the assistance of Sobotka Company, Inc.

Model Summary: A static linear programming model which calculates optimal solutions in two steps. The Refinery Yield Models (RYMs) estimate refined product yields; these yields are used in the Oil Refining and Distribution (ORAD) model, which determines the optimal refinery and transportation activities which maximize refinery gross margins.

Submodels: The Refinery Yield Models (RYMs) contain detailed representations of refinery processes and output production. ORAD is a static, regional, linear programming simulation of the domestic refining and distribution industry. Both models contain three basic programs: a preprocessor and matrix generator; a program which calls the Mathematical Programming System (MPS-III) to solve the linear programming program; and a report writer.
Equations: The refinery yield model contains approximately 350 equations. (The actual number of equations used depends upon the application).
Variables: The linear program matrix contains about 1100 variables and 8300 elements. The yield models require information on process unit technology, inputs, capacities, policy variables and product sales and revenues; they result in a list of product mixes and costs, and process unit material balances. ORAD uses the yield information, along with transportation data and demand estimates, to provide materials balances by region, refinery costs, yields and product distributions.

Applications: Used to evaluate the costs and benefits of reducing lead in gasoline, and as the basis for some proposed rulemaking on the subject by the U.S. Environmental Protection Agency.

Time Coverage: 1982-1988.
Regions: 9 regions, based on the 13 Bureau of Mines Refining Disricts; plus refineries in U.S. territories and non-U.S. Carribean capacity.
Industries: Petroleum refining and distribution.

Acquisition Information:

Availability: Publicly available.
Computer System/Language: Runs on an IBM 370/3033; the matrix generators and report writers are coded in the Omni computer language, and the optimizer programs are coded in the assembler language system. TSO and SUPERWYLBUR are used as interactive command languages (for data entry and modification at a computer terminal).

TABLE III-14. REMS -- THE REFINERY EVALUATION MODELING SYSTEM (continued)

Costs: DOE would provide tapes with model information for the approximate cost of the tape ($100-200). To run the program, the ARB must obtain the software (for matrix generation, optimization, and report writing) from dealers. Because the model is large, it will require significant amounts of computer time (35-40 CPU seconds for each RYM or ORAD run). Acquisition of California-specific data, and model modifications to include residuals and to tailor REMS to the California economy, must also be included.

References: Documentation on the model and database are contained in U.S. Department of Energy, Energy Information Administration (1984a, 1984b). Applications to lead reduction in gasoline are shown in Schwartz et al. (1984) and in U.S. Environmental Protection Agency (1984).

TABLE III-15. RPMS -- THE REFINERY AND PETROCHEMICAL MODELING SYSTEM

Authors: Bonner and Moore Associates, Inc.
Background: Company developed.

Model Summary: A linear programming based refinery modeling system. Contains data on: the current installed capacity of each refining process in each PAD district; yields and stream qualities for domestic and foreign crude oils; process investment data; and stream properties for product blending representation.

Submodels: Submodels are available for each commercially-used refining process.
Equations: NA
Variables: Requires as input: detailed descriptions of available raw materials and demands for refined products; process capacities; crude segregation patterns to be modeled; product property specifications, options for stream disposition; and process capacity investment.

Applications: The Department of Energy used the model to estimate supplies of leaded and unleaded gasoline in 1980. The Army used the model to project the availability of gasoline and distillates in 1975-85. In 1975, an interdepartmental (DOT, EPA, NSF, FEA and ERDA) study estimated the impact of engine development trends on the refining industry. The effects of alcohol fuel use in 1990 were examined for DOE. How changes in allowable vapor pressure of gasoline during the summer might affect process investments and refinery costs in California was examined in a study for the California Air Resources Board.

Time Coverage: 1980 (DOE), 1975-85 (U. S. Army), 1995-2000 (DOT et al.), 1990 (DOE), 1985-90 (ARB).
Regions: Entire U.S. was examined in all studies except the California Air Resources Board report, where the state of California was the focus.
Industries: Petroleum refining

Acquisition Information:

Availability: Proprietary; access to RPMS or to models generated via RPMS can be provided through licensing agreements or through consulting/study services provided by the firm.
Computer System/Language: Can run on an IBM (if it can support the OS version of MPSX/370) or a Univac (1100 Series); most programs written in the Bonner & Moore GAMMA language. Requires the support of a mathematical programming system such as FMPS (for Univac computing hardware) or MPSX (for IBM computers).
Costs: Dependent upon agreement arrangement chosen.

TABLE III-15. RPMS -- THE REFINERY AND PETROCHEMICAL MODELING SYSTEM (continued)

References: The gasoline supply estimates for DOE appear in Tukenmez (1978), and the Army study is documented in Bonner and Moore Associates, Inc. (1974). A summary of the engine trends analysis appears in Dickson et al. (1982). The possible impacts of alcohol fuels are explored in Dickson et al. (1983), and estimates of the refining industry's ability to meet future demands appear in Bryant et al. (1981). The California study is described in Bonner and Moore Management Science (1983).

A history of refinery modeling is presented in Moore et al. (1983). Discussion of the RPMS system is available in Bonner and Moore Management Science (no date).

TABLE III-16. THE RESOURCES FOR THE FUTURE (RfF) / RUSSELL MODEL

Authors: Clifford S. Russell
Background: Model was developed as one of several industry models for the Quality of the Environment Program at RfF.

Model Summary: Linear programming model of a "typical" petroleum refinery plant. The model maximizes profits subject to product prices, operating costs, and technical constraints. The model tableau contains over 200 rows, and incorporates technical information on crude desalting and fractionation, gasoline production and blending, other petroleum products, and waste production.

Submodels: Basic refinery model contains a gasoline production, hydrogen treating, and sour gas desulfurization subsystems.
Equations: Size of LP matrix depends upon case under study.
Variables: Documented in Russell (1973). Requires detailed descriptions of available raw materials and demands for refined products; process capacities; crude segregation patterns to be modeled; product property specifications, options for stream disposition; and process capacity investment.

Applications: Used to evaluate a number of policy options, including emission charges, upper limits on discharges of particular pollutants, and greater kerosene production. Applied to a "typical" refinery of the early 1970's -- was not an industry or national model.

Time Coverage: NA
Regions: NA
Industries: Petroleum refining (limited to a "typical" refinery).

Acquisition Information:

Availability: Publiclyavailable
Computer System/Language: IBM Mathematical Programming System (MPS)
Costs: Computer cards used in original study could be made available to the ARB. Documentation is available in Russell (1973). Model is relatively large, and would require significant CPU time per run. Updated refinery technology would need to be included, as would California-specific information.

References: Russell (1973), and Howe _et al_. (1971).

TABLE III-17. THE RICE/SMITH MODEL

Authors: Patricia L. Rice, V. Kerry Smith

Background: Rice developed the model as part of her Ph.D. dissertation at the State University of New York at Binghamton (Smith was one of her thesis advisors).

Model Summary: An econometric model of the petroleum industry (crude production, reserves, refinery products). Estimation methods include OLS, GLS, and two-stage estimation (reflecting nonlinearities and autocorrelation) where appropriate. Refinery outputs and prices are determined simultaneously by market forces, while domestic crude output is determined separately in a block-recursive format.

Submodels: Crude oil production sector and refinery sector.

Equations: Entire model has 42 equations (25 are identities): production sector contains 17 equations (6 stochastic, 11 identities); refining sector has 23 equations (11 stochastic, 12 identities).

Variables: 62 variables (21 exogenous, 41 endogenous)

Applications: Used to evaluate the effects on prices, reserves, production and demand of four policy options: elimination of the oil depletion allowance, further price increases by OPEC, deregulation of domestic wellhead crude prices, increased gasoline prices, and gasoline rationing. Forecasts to 1985 under two scenarios are compared with Federal Energy Administration forecasts for the same period.

Time Coverage: Annual data: 1946-73 (estimates); 1974-75 (simulations); 1974-85 (forecasts).

Regions: United States

Industries: Petroleum production and refining

Acquisition Information:

Availability: Publicly available list of equations and data sources.

Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).

Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running a simultaneous-equation model.

References: Rice (1976), and Rice and Smith (1977).

TABLE III-18. THE ROLLINS MODEL

Authors: John B. Rollins
Background: Model developed as part of Ph.D. dissertation at Texas A&M.

Model Summary: Econometric model of demand and supply associated with petroleum refining and consumption.

Submodels: --
Equations: 14
Variables: 24 endogenous, 15 exogenous.

Applications: applied to the U.S. economy.

Time Coverage: 1935-73.
Regions: Entire U.S.
Industries: Petroleum refining and transportation.

Acquisition Information:

Availability: Publicly available list of equations and data sources.
Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).
Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running regression analysis.

References: Rollins (1978).

TABLE III-19. THE SWEENEY MODEL

Authors: J. L. Sweeney
Background: Model developed at the Energy Modeling Forum (Stanford, CA)

Model Summary: An econometric model of gasoline usage which includes a number of Federal policy variables (e.g., miles-per-gallon, gas taxes, etc.). The equations are estimated in linear and log-linear forms, with and without elasticity constraints across equations.

Submodels: NA
Equations: Approximately 20 (Some equations are alternative specifications of the same concept).
Variables: Documented in references listed below. Estimates gasoline demand, fuel efficiency, miles driven as a function of fuel price, income, automobile efficiency, and several policy variables.

Applications: Used to estimate the impacts on gasoline consumption of several Federal policy options, including: new car average fuel efficiency standards; a gasoline tax; crude oil price controls; emissions standards; and a 55-mph speed limit.

Time Coverage: 1957-1974 (sample period), 1975-1985 (forecasts).
Regions: Entire U.S.
Industries: Gasoline consumption.

Acquisition Information:

Availability: Publicly available list of equations and data sources.
Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).
Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running regressions on the model.

References: Sweeney (1979 and 1983).

TABLE III-20. THE TEXAS AIR CONTROL BOARD MODEL

Authors: Bill Stewart (Frank Spuhler did petroleum refining case).
Background: Study commissioned by Texas Governor's Energy Advisory Council.

Model Summary: Study forecasts emissions for various Texas industries under three possible scenarios (low, medium, high growth). Emissions estimates are based upon current industry capacities and emission levels, plus assumptions about future growth in the industry. (The future growth estimates are based upon a survey of Texas refineries).

Submodels: NA
Equations: NA (Forecasts were simple projections of current emissions levels).
Variables: Emissions, industrial capacity.

Applications:

Time Coverage: 1975-2000.
Regions: Texas
Industries: Besides petroleum refining, seven other industries were analyzed.

Acquisition Information:

Availability: Public information.
Computer System/Language: NA
Costs: Negligible -- can get information from existing references.

References: Study described in Stewart (1975); survey upon which results were based is in Texas Mid-Continent Oil and Gas Association (1974).

TABLE III-21. THE TURNER-MASON-SOLOMON (TMS) MODEL

Authors: Turner, Mason and Associates.
Background: Company developed model.

Model Summary: Refinery model that employs a linear programming algorithm to meet fixed product demands.

Submodels: NA
Equations: NA
Variables: NA

Applications: Used to describe the effects of alternative tariff policies on the U.S. refinery industry assuming crude oil decontrol.

Time Coverage: 1980
Regions: The entire U.S. and 15 Model Areas composed of one or more states.
Industries: Petroleum refining.

Acquisition Information:

Availability: Proprietary.
Computer System/Language: --
Costs: --

References: Many studies are not in the public domain; the study of tariff policies is described in McGregor (1980).

TABLE III-22. THE UNIVERSITY OF HOUSTON MODEL

Authors: James Calloway, Russell Thompson, others.
Background: The RfF/Russell model was updated by the University of Houston and used for their integrated industry modeling efforts.

Model Summary: The "integrated" model uses linear programming to describe material flows and production processes for ten specific industries. The refinery model is a version of the Russell/Resources for the Future model, but is expanded to represent the entire petroleum refining industry rather than just a typical plant.

Submodels: Includes submodels for petroleum refining, chemicals, and electric power generation.
Equations: The entire model contains more than 1200 rows and 2100 columns.
Variables: For the refinery model, technical information on crude desalting and fractionation, gasoline production and blending, other petroleum products, and waste production is included.

Applications: A number of waste discharge standards, fuel use restrictions and pricing policies for the fossil energy sector were evaluated.

Time Coverage: Forecasts through 1985.
Regions: The entire U.S., and the state of Texas.
Industries: Besides refining, includes chemicals and electric power generation.

Acquisition Information: Two options are possible. The model could be obtained through the University of Houston, or use of the system could be acquired through Russell Thompson's firm (OPCON).

Availability: Publicly available
Computer System/Language: Fortran
Costs: Computer subroutines used in the original studies, and documentation of variables and subroutines, are available in Thompson et al. (1978). Model is relatively large, and would require significant CPU time per run. California-specific information would need to be developed and included.

References: Calloway et al. (1976), and Thompson et al. (1976 and 1978).

TABLE III-23. THE UNIVERSITY OF TEXAS AT AUSTIN MODEL

Authors: David Kendrick, Alexander Meeraus, Jung Sun Suh, others
Background: The model was developed at the Center for Energy Studies at the university.

Model Summary: A dynamic spatial process model -- also known as a multiperiod, multiregion, multiproduct, multiprocess mixed integer linear programming model -- was developed to minimize total costs subject to technical constraints, fixed demands, and other exogenous factors. Because the model includes time explicitly, there are more stringent limits on the technical information which is included.

Submodels: Includes crude and LPG raw supply, a refinery process model, market demand, and an objective function.
Equations: The matrix of the model is 542 X 818.
Variables: Documented in the references listed below.

Applications: There were three distinct applications: to a familiar textbook oil refinery problem, to the Texas Gulf Coast refining complex, and to the oil refining and petrochemical industries in Korea. For the Texas application:

Time Coverage: 1983-1997, in three five-year increments.
Regions: The U.S. Gulf Coast, the rest of the U.S., Europe.
Industries: Petroleum supply, production and refining.

Acquisition Information:

Availability: Publicly available from the University of Texas.
Computer System/Language: Used on the University of Texas CDC computer. The model used the GAMS software language and is linked for computation with the non-linear programming algorithm MINOS.
Costs: Software and documentation are available from the University of Texas, and the model is documented in Appendix B of Langston (1983). Model is smaller than many linear programming models, so will require a medium amount of CPU time to run. California specific data will need to be generated and added.

References: The comparison with a textbook case appears in Kendrick et al. (1981), the Texas application is documented in Langston (1983a, 1983b), and the Korean example appears in Suh (1981).

TABLE III-24. THE UNIVERSITY OF LONDON MODEL

Authors: The Energy Research Unit, Queen Mary College
Background: --

Model Summary: NA

Submodels: NA
Equations: NA
Variables: NA

Applications: Used to examine four policy options: satisfying some U.S. natural gas demand with oil; prohibiting new refinery construction on the U.S. East Coast; enforcing lower sulfur limits in the U.S.; and assuming Alaskan crude oil becomes available.

Time Coverage: NA
Regions: NA
Industries: NA

Acquisition Information:

Availability: NA
Computer System/Language: NA
Costs: NA

References: Deam _et al_. (1973)

TABLE III-25. THE VERLEGER/SHEEHAN MODEL
(also known as the HVS -- Houthakker/Verleger/Sheehan -- model)

Authors: Philip K. Verleger, Jr., Dennis P. Sheehan and Hendrik S. Houthakker
Background: Sponsored by the U.S. Environmental Protection Agency and the Council on Environmental Quality, with much of the empirical work carried out at Data Resources, Inc. (DRI).

Model Summary: An econometric model of the demand for gasoline. This demand is split into two components -- a short run demand, which depends on vehicle usage, and a longer run demand which also allows for purchase of a different car in response to changing prices.

Submodels: NA
Equations: NA
Variables: Documented in reference listed below.

Applications: The model was exercised on 1974-75 information, and compared with actual gasoline usage data.

Time Coverage: 1974-75 (forecasts).
Regions: Entire U.S.
Industries: --

Acquisition Information:

Availability: Algorithms and data located at Data Resources, Inc., Lexington, Massachusetts.
Computer System/Language: Computational algorithm embodied in a set of FORTRAN programs residing in the Burroughs 7700 computer operated by DRI.
Costs: Subject to negotiation with DRI.

References: Verleger and Sheehan (1976)

TABLE III-26. THE WILKINS MODEL

Authors: John R. Wilkins
Background: Prepared for the Northwest Energy Policy Project

Model Summary: The study used input-output (I-O, or interindustry) analysis to estimate how a change in output in any particular sector changed output in all other sectors.

Submodels: NA
Equations: NA
Variables: NA

Applications: Used on the Pacific Northwest region to determine how energy policies affected production, employment, consumption and regional exports.

Time Coverage: 1972-85 (forecasts).
Regions: The Pacific Northwest region (Washington, Oregon, and Idaho).
Industries: 26 sectors, based on two-digit SIC codes; one of these sectors is petroleum refining.

Acquisition Information:

Availability: I-O modeling undertaken by a private firm; model is proprietary.
Computer System/Language: --
Costs: --

References: Wilkins (1978).

TABLE III-27. THE WILKINSON MODEL

Authors: Jack W. Wilkinson
Background: Model developed as part of Ph.D. dissertation at Temple University.

Model Summary: Econometric model of crude oil and refined petroleum demand and supply.

Submodels: --
Equations: 15 structural equations, 8 reduced-form equations, several identities.
Variables: 23 endogenous, 53 exogenous

Applications:

Time Coverage: 1965-70 (sample), 1971-76 (forecasts).
Regions: Entire U.S.
Industries: Petroleum production and refining.

Acquisition Information:

Availability: Publicly available list of equations and data sources.
Computer System/Language: Not applicable (Due to small size of model, equations can be readily entered on ARB system directly).
Costs: Very low. Model has no direct acquisition costs. Primary expenses will be for installation of equations on system, acquisition of California-specific data, and possible acquisitions costs for appropriate software for running regression analysis.

References: Wilkinson (1974).

IV. CHOOSING A MODEL

Whether or not a particular model is appropriate depends upon the purpose for which it will be used. A model may be extremely good at determining daily refinery production, yet it may not be at all suitable for setting long-range pollution control goals. Chapter III identified several models of the petroleum refinery industry; which one (if any) is most applicable depends upon the needs of the Air Resources Board. Those needs must be carefully identified and articulated, because they are very likely to conflict: a need for detail may make one model the most relevant, while a need for low cost or ease of use may point to another modeling option.

This chapter summarizes the criteria which were used to choose among the petroleum refinery models identified in Chapter III. A general list of ARB needs is presented first, followed by more specific measures of each item on the list. When criteria conflict, an indication of which criterion was more important (and why) is given.

A. General Criteria

What attributes should an economic model of the petroleum refining industry have to provide the ARB with useful information upon which to make environmental policy decisions? Answers to this question would include the following:

An Ability to Include a Variety of Policy Options. This may sound almost trivial, but many models implicitly assume that economic and policy conditions do not change. Such models are unacceptable for further consideration.

Accuracy. This attribute contains two elements:

> Representativeness. The model should closely approximate economic conditions and aspects of the petroleum industry in California.
>
> Statistical Accuracy. According to various econometric and statistical tools, the model and individual equations should closely simulate actual situations.

Availability. The model, data, and documentation should be available to Air Resources Board staff for further analysis and evaluation.

Detail. Disaggregation at the refinery level, so that different sizes of refineries may be analyzed, is preferable. Regional disaggregation would also be helpful, but is not considered as crucial to the current study as disaggregation by refinery type.

Time Horizon. The model should be suitable for longer-range (10-15 year) planning purposes.

Cost Effectiveness. For two models with similar capabilities, the less expensive model will be chosen.

B. Specific Criteria

Each general attribute includes several specific measures. For example, there are several types of cost to consider -- acquisition costs (including the model, associated computer equipment and user documentation), costs incurred each time a specific case is evaluated (such as data set-up costs and computer operation time), and other recurring expenses such as model and documentation updating costs. This section details the measures which will be used to evaluate alternative models.

Accuracy/Representativeness. The model should reflect conditions in the state of California as closely as possible; both supply and demand factors should be included. On the supply side, the following factors should be included or includable:

- mix of crude oil inputs
- relative prices of refinery inputs
- existing and anticipated stationary source emission standards
- mix of refinery types and sizes.

On the demand side, the following conditions should be represented:

- mix of refinery outputs demanded
- relative prices of refinery outputs
- prices of substitutes
- anticipated trends in output consumption and prices
- incomes and demographic characteristics.

Accuracy/Statistical Accuracy. It is often argued that the "true test" of a model is its ability to forecast outside the sample period. If model extrapolations yield good predictions, more confidence can be placed in the ability of the model to predict. Thus, any information on the model's ability to forecast outside of the time period considered in the study (the "sample period") will be a primary indication of the model's statistical accuracy.

However, it is not always possible to conduct an evaluation of a model outside the sample period, because of lack of data or the nature of the estimation technique used.1/ In such cases, evaluation is confined to an analysis of the model's performance as a whole over the sample period, using conventional goodness-of-fit measures.

In this study, four different criteria of goodness-of-fit2/ are considered:

- Mean Absolute Error (MAE) -- the average absolute deviation of the predicted from the actual values of the endogenous variables.

- Mean Absolute Percentage Error (MAPE) -- the MAE divided by the mean value of the endogenous variable. MAPE normalizes the errors.

- Root Mean Squared Error (RMSE) -- the square root of the average squared deviations of the predicted from the actual values. RMSE attaches lower weights to smaller deviations, and greater weights to deviations exceeding unity.

- Theil's Inequality Coefficient (U) -- uses information on the absolute discrepancy between predicted and actual changes. The numerator is the RMSE, and the denominator is an expression which confines the values of U to the closed interval between zero and one. The inequality coefficient can be decomposed into three terms which indicate the proportions of inequality attributable to bias, variance, and covariance.

For several of the models under consideration, it will not be possible to calculate these measures of goodness-of-fit. In those cases, the alternative approach will include an evaluation of the econometric techniques used upon the data, and the quality of the data used. Factors which will be considered include:

- estimation technique;

- likelihood of inefficient or inconsistent estimators (e.g., through autocorrelation of data or presence of lagged dependent variables);

- missing variables.

Availability. Ideally, the model should be non-proprietary, so that it may be used by ARB staff. However, on-line availability (where the specific equations of the model are proprietary, but the model may be put on a computer and run as a "black box," without resorting to Requests for Proposals every time a run is made) would be sufficient.

Detail. Here, two specific considerations are most important: the model should accomodate a wide variety of refinery types and sizes, and it should be able to model the effects of air pollution control regulations on the industry. Thus, the factors which are most important are:

- ability to model various refinery configurations

- ability to track pollution control changes through the refinery process.

Other factors which would be useful, but which are not as high a priority, are:

- ability to disaggregate by region

- ability to disaggregate by product mix

- ability to disaggregate by consumer category.

Time Horizon. A medium to long range (10-15 year) planning horizon is most desirable. Short-run (1-2 years or less) models are not acceptable.

Cost Effectiveness. Costs may be disaggregated into two general categories: initial costs, and recurring costs. Initial costs would include:

- model acquisition costs
- computer equipment and operating system costs associated with installation
- initial user documentation and user training

There are also costs which are incurred periodically. These include:

- data set-up costs for each case that is evaluated
- computer operations costs incurred each time a case is run
- model, data and documentation updating costs.

C. Identifying the Most Important Attributes

Which attributes are most important? A model which may be expensive to acquire may also be very detailed, efficient (in usage of computer time) and accurate. Choosing among models with very different characteristics is a step which must be taken cautiously.

The criteria shown in Sections A and B were discussed extensively with ARB personnel. These discussions resulted in the following decisions:

- there are three criteria which would immediately disqualify a model from further consideration, if any one of the three criteria are not met. These criteria are:
    - an ability to include air pollution control,
    - a model which is not completely proprietary, and
    - an ability to handle medium-to-long-range time horizons.
- the general list of criteria (presented in Section A) appear in the approximate order of importance. Thus, accuracy is more important than detail, and both are more important than cost.
- within each general category, the following rankings of specific criteria prevail:
    - in the accuracy category, the inclusion of both supply and demand conditions is most important
    - in the availability category, proprietary models without on-line access are unacceptable
    - regarding detail, the ability to model a variety of refinery types is most important

- a time horizon of less than two years is unacceptable

- in the cost-effectiveness category, initial costs are considered more important than recurring costs.

These criteria are now used to evaluate the various models discussed in the previous chapter.

FOOTNOTES TO CHAPTER IV

1. Simultaneous estimation techniques or models attempting to determine values for a large number of parameters often result in an insufficient number of degrees of freedom for an ex post evaluation outside of the sample period. For more information, see Theil (1978), Chapter 22.

2. Brief mathematical descriptions of each of these measures may be found in Rice (1976), Chapter 6. More detail on each of the concepts may be found in Theil (1978), Chapter 22.

V. EVALUATING THE MODELS

Twenty seven models are of potential interest to this study; the name of each model was listed in Table II-4, and detailed information on each model was given in Tables III-1 through III-27. The models vary enormously in their coverage, detail, availability, and previous usage. The characteristics of the models must now be compared with the needs of the ARB, so that an appropriate model (or set of models) may be chosen.

The comparison is undertaken in two stages. First, those criteria with "veto power" are applied; if a model is unacceptable for any reason, it will not be included in the second-stage analysis. The second round of analysis includes detailed information on the models regarding their abilities to meet ARB needs.

A. Stage One Comparisons

In Chapter IV, three criteria were listed which would immediately disqualify a model from further consideration if they were not met. These criteria were:

- an ability to include policy considerations,
- a model which is not completely proprietary, and
- an ability to handle medium-to-long-range time horizons.

If any one of these capabilities is not available in a model, it is removed from further consideration.

These three "veto" criteria removed thirteen models from further analysis. The first criterion -- an ability to include various environmental policy options -- dropped seven models from the list (DRI, Hudson/Jorgenson, Lakhani, Sweeney, the Texas Air Control Board, Wilkins, and Wilkinson). These were the "top down" models discussed in the first section of Chapter III; because top-down models must assume so many factors do not change, they are inappropriate for the types of environmental analysis the ARB will be conducting.

The second criterion -- availability -- removed six more models from further consideration. Four of the models (Gulf, Kellogg, Parsons, Turner-Mason) were company-developed, proprietary models; on-line usage of the results was not a possibility. Two more models (the French models, and the University of London model) were dropped from further consideration because even simple documentation was unobtainable.

The third criterion -- time horizon -- would remove short-run models from further consideration. The Wilkinson model, a short-run macroeconometric model, would have been dropped from further consideration on the basis of this criterion if it had not already been ousted on the policy-inclusion criterion.

Table V-1 enumerates the petroleum refining models which are still potentially applicable after the first screening. Nearly half the candidates have been removed from further consideration; the remaining fourteen models are now analyzed in detail.

TABLE V-1. LIST OF CANDIDATE MODELS AFTER FIRST SCREENING

The Adams/Griffin Model
The Arthur D. Little (ADL) Model
The Chou Model
The Kennedy Model
The Pace LP Modeling System (PMS)

The Pagoulatos Model
REMS -- The Refinery Evaluation Modeling System
RPMS -- The Refinery and Petrochemical Modeling System
The Resources for the Future (RfF) / Russell Model
The Rice/Smith Model

The Rollins Model
The University of Houston Model
The University of Texas at Austin Model
The Verleger/Sheehan Model

B. Stage Two Comparisons

The fourteen petroleum refining models listed in Table V-1 are evaluated in detail in Tables V-2 through V-15. Each of the main criteria are listed in the order discussed in Chapter IV; the subsidiary criteria follow.

In the Accuracy/Representativeness category, one model (Verleger/Sheehan) is a demand-side model, five are supply-only models (ADL, PMS, REMS, RPMS, and Russell), and the rest include some portions of demand and supply. Very few demand factors are included in any of the models, and only three -- ADL, RPMS, and the University of Houston -- include emissions standards for stationary sources. (This does not mean that emissions information cannot be added to some of the models -- for process models, emissions information can be readily included by placing additional equations in the model -- only that emissions information has not been included).

Relatively little information is available in the Accuracy/Statistical Accuracy category. A number of measures have been developed to evaluate how well a model simulates or predicts variable values. Some of the more widely used measures are Mean Absolute Error (MAE), Mean Absolute Percentage Error (MAPE), Root Mean Square Error (RMSE) and Theil's U coefficient (U). The models which were developed as a portion of a doctoral dissertation (Adams/Griffin, Rice/Smith) have the most detailed calibration measures. Many of the other models merely present their results, or compare their results with forecasts made by government agencies such as the Federal Energy Administration. In models where no goodness-of-fit measures are available, information on the estimation technique is included. Ordinary Least Squares (OLS) is the simplest technique: each equation is estimated singly and independently. However, unless a number of rather stringent assumptions hold, OLS estimation techniques produce incorrect parameter estimates. When the assumptions of OLS are not valid, more complex estimation methods such as Two Stage Least Squares (2SLS), Three Stage Least Squares (3SLS), Generalized Least Squares (GLS) or Instrumental Variable (IV) techniques need to be used: which one is chosen depends upon the estimation problems likely to appear in the model. Some equation systems are so tightly interrelated that all equations must be estimated at the same time; other systems can be "compartmentalized" into groups of equations that must be evaluated together, but the various compartments (known as "blocks") may be estimated separately. In the latter type of equation system, techniques such as block recursive modeling and iterative techniques (such as Cochrane-Orcutt iterative techniques) may be used. More information on the goodness-of-fit measures, estimation techniques and modeling problems may be found in Theil (1978).

The availability of the models varies widely. Some are available for the asking or for the price of a computer tape (Russell, REMS). Some are small models whose equations are documented in the open literature, and can be readily recreated on the ARB computer system (Pagoulatos, Rollins). Others would probably be available only through on-line access (Pace, RPMS).

The detail in the models also varies substantially. Several of the smaller models combine all U.S. refining into one variable (Kennedy, Rice, Rollins). In contrast, the linear programming models can represent almost any refinery size, configuration and product mix. Yet the LP models have very little demand detail associated with them; most LP modelers rely on an economic forecasting company for demand estimates, then take the acquired demand estimates as given inputs when they run the models. A few models (such as Chou and the University of Texas at Austin Model) compromise between the two extremes: a relatively small number of both supply and demand variables are included. Often, the limited model size allows simultaneous equation estimation or dynamic modeling.

Most of the models have a medium-range time horizon, with the very smallest and the simultaneously estimated models having a somewhat shorter time horizon. Some of the large simultaneous models are more limited because estimation errors can be spread across equations and magnify over time. Alternatively, variables missing or assumed to be unimportant in the smaller models can create large errors in forecasts as the time horizon expands.

Model costs show a tremendous variation. The smaller, publicly documented models (Pagoulatos, Rollins) could easily be recreated on the ARB computer system, and would have relatively minor data acquisition and update costs. The LP models developed by private firms would be relatively expensive to acquire, but would have high quality training and documentation associated with them. A subset of the models (REMS, Russell) could be acquired for almost nothing, but would require large investments of time by ARB personnel for set up, since little support would be available.

Detailed information on the criteria for each of the models is given in Tables V-2 through V-15. Where possible, a point of contact is also given, so that further information and clarification may be obtained.

A summary of the information in Tables V-2 through V-15 is given in Table V-16. The first column reiterates the most important characteristic of the "Accuracy/Representativeness" criterion; models are identified as supply-only, demand-only or supply-and-demand (D&S) models. The second column indicates the available information for the "Statistical Accuracy" criterion: little information is available, but the Adams/Griffin, Rice/Smith and Verleger/Sheehan models are all very good, while the Arthur D. Little model does an acceptable job. (The error in the ADL model is far greater in PAD V -- the region in which California is located -- than in any other region). All of the models are either publicly available, or available in some limited manner subject to negotiation with the model owner.

The amount of detail varies widely; Table V-16 indicates whether or not emissions information is included, and how detailed the other information is in the model on a "good-fair-poor" basis. The information available in four of the models -- Kennedy, Pagoulatos, Rice, and Rollins -- is so aggregated or so scant that the models should be excluded from further consideration.

The remaining three columns in Table V-16 provide information on the time horizon of the model and on initial and recurring costs. Most of the models have a medium-range (10-15 year) horizon, although a few are in the short-to-medium range (3-5 years) time frame. The combinations of initial and recurring costs are varied: the smaller models and publicly available models tend to have lower initial costs, and the larger and simultaneously determined models tend to have higher recurring costs.

Ideally, the ARB would like to have one (or more) models with "D&S-Good-Public-Yes-Good-Medium-Low-Low" entries listed in Table V-16. However, one of the main conclusions that can be drawn from the table is that there are no California-specific economic models of the petroleum refining industry currently available. Only a few of the models -- Kennedy, Pagoulatos, Rice and Rollins -- are so aggregated that they may be excluded from further study. The issue then becomes one of using the "bits and pieces" that are currently available to build a model that IS a California specific economic model of petroleum refining. This is the effort which is outlined in the final chapter.

TABLE V-2. EVALUATION OF THE ADAMS/GRIFFIN MODEL

Accuracy/Representativeness.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	no
- prices of substitutes	no
- trends in output consumption and prices	no
- incomes, demographic characteristics	no
Accuracy/Statistical Accuracy.	
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	2% on average (.65 - 4.69% range)
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	Ordinary Least Squares
- likelihood of incorrect estimators	Low, due to recursive model structure
- missing variables	NA
Availability	Subject to negotiation

TABLE V-2. EVALUATION OF THE ADAMS/GRIFFIN MODEL
(continued)

<u>Detail</u>

high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	yes
- disaggregation by consumer category	no

<u>Time Horizon</u>	medium range (5-10 years)

<u>Cost Effectiveness</u>

initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average

Contact: Dr. James M. Griffin
Economics Department
Texas A&M University
College Station, Texas 77843
(409) 845-9950

TABLE V-3. EVALUATION OF THE ARTHUR D. LITTLE (ADL) MODEL

Accuracy/Representativeness.	
supply and demand factors included	supply only
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	yes
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	NA
- relative prices of refinery outputs	NA
- prices of substitutes	NA
- trends in output consumption and prices	NA
- incomes, demographic characteristics	NA
Accuracy/Statistical Accuracy.	
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	"Calibrated:" clusters scaled up; deviated .2 - 6.8% from PAD
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	NA (Used LP model)
- estimation technique	--
- likelihood of incorrect estimators	--
- missing variables	--
Availability	Subject to negotiation

TABLE V-3. EVALUATION OF THE ARTHUR D. LITTLE (ADL) MODEL (continued)

<u>Detail</u>	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	yes (PAD Districts)
- disaggregation by product mix	yes (gasoline emphasis)
- disaggregation by consumer category	no
<u>Time Horizon</u>	medium range (5-10 years)
<u>Cost Effectiveness</u>	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average

Contact: Mr. John Felten
(617) 864-5770

TABLE V-4. EVALUATION OF THE CHOU MODEL

Accuracy/Representativeness.

supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	yes
- prices of substitutes	no
- trends in output consumption and prices	no
- incomes, demographic characteristics	yes

Accuracy/Statistical Accuracy.

ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	Ordinary Least Squares
- likelihood of incorrect estimators	Low, due to recursive model structure
- missing variables	NA

Availability	Publicly available.

TABLE V-4. EVALUATION OF THE CHOU MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	no
lower priority:	
- disaggregation by region	yes (PAD Districts)
- disaggregation by product mix	yes
- disaggregation by consumer category	no
Time Horizon	medium range (5-10 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	low
- installation costs	average
- documentation and user training	average/high (no support)
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average/high (no support)

Contact: none

TABLE V-5. EVALUATION OF THE KENNEDY MODEL

<u>Accuracy/Representativeness</u>.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	yes
- prices of substitutes	yes
- trends in output consumption and prices	yes
- incomes, demographic characteristics	yes
<u>Accuracy/Statistical Accuracy</u>.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	Two Stage Least Squares
- likelihood of incorrect estimators	High, due to simultaneous model structure
- missing variables	NA
<u>Availability</u>	Subject to negotiation

TABLE V-5. EVALUATION OF THE KENNEDY MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	no (all U.S.)
- disaggregation by product mix	yes
- disaggregation by consumer category	no (except by nation)
Time Horizon	medium range (5 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average
- documentation and user training	above average
recurring costs:	
- CPU time and set-up costs	above average (simultaneous)
- model, data and documentation updating	average

Contact: Data Resources, Inc.
(617) 863-5100

TABLE V-6. EVALUATION OF THE PACE LP MODELING SYSTEM (PMS) MODEL

Accuracy/Representativeness.	
supply and demand factors included	supply only
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	yes
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	NA
- relative prices of refinery outputs	NA
- prices of substitutes	NA
- trends in output consumption and prices	NA
- incomes, demographic characteristics	NA
Accuracy/Statistical Accuracy.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	NA
- likelihood of incorrect estimators	NA
- missing variables	NA
Availability	Subject to negotiation

TABLE V-6. EVALUATION OF THE PACE LP MODELING SYSTEM (PMS) MODEL (continued)

Detail	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	yes (PAD Districts)
- disaggregation by product mix	yes
- disaggregation by consumer category	no
Time Horizon	short/medium range (5 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average/high
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average

Contact: Mr. Dan Foley
(713) 965-0311

TABLE V-7. EVALUATION OF THE PAGOULATOS MODEL

Accuracy/Representativeness.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	no (entire industry)
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	yes
- prices of substitutes	no
- trends in output consumption and prices	no
- incomes, demographic characteristics	no
Accuracy/Statistical Accuracy.	
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	Block recursive in two blocks (2SLS,3SLS)
- likelihood of incorrect estimators	Low, due to recursive model structure
- missing variables	Highly likely, due to small model size.
Availability	Publicly available.

TABLE V-7. EVALUATION OF THE PAGOULATOS MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	no
- tracks emissions changes	no
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	yes
- disaggregation by consumer category	no
Time Horizon	medium range (5-10 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	low
- installation costs	low
- documentation and user training	low/average
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	low/average

Contact: none

TABLE V-8. EVALUATION OF THE REMS MODEL

<u>Accuracy/Representativeness</u>	
supply and demand factors included	supply only
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	NA
- relative prices of refinery outputs	NA
- prices of substitutes	NA
- trends in output consumption and prices	NA
- incomes, other demographic characteristics	NA
<u>Accuracy/Statistical Accuracy</u>	No information
ability to forecast outside sample period:	
- MAE	
- MAPE	
- RMSE	
- U	
performance over sample period:	
- MAE	
- MAPE	
- RMSE	
- U	
econometric techniques:	
- estimation technique	
- likelihood of incorrect estimators	
- missing variables	
<u>Availability</u>	Public

TABLE V-8. EVALUATION OF THE REMS MODEL
(continued)

<u>Detail</u>	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	13 BOMRD Districts
- disaggregation by product mix	yes
- disaggregation by consumer category	no
<u>Time Horizon</u>	medium range (5-10 years)
<u>Cost Effectiveness</u>	
initial costs:	
- model acquisition costs	low for LP
- installation costs	average (no support)
- documentation and user training	average (no support)
recurring costs:	
- CPU time and set-up costs	low/average
- model, data and documentation updating	average (no support)

Contact: John Conti
(202) 252-5996

TABLE V-9. EVALUATION OF THE RPMS MODEL

<u>Accuracy/Representativeness</u>.	
supply and demand factors included	supply only
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	yes
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	NA
- relative prices of refinery outputs	NA
- prices of substitutes	NA
- trends in output consumption and prices	NA
- incomes, demographic characteristics	NA
<u>Accuracy/Statistical Accuracy</u>.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	NA
- likelihood of incorrect estimators	NA
- missing variables	NA
<u>Availability</u>	Subject to negotiation

TABLE V-9. EVALUATION OF THE RPMS MODEL
(continued)

<u>Detail</u>	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	yes (CA, PAD Districts)
- disaggregation by product mix	yes
- disaggregation by consumer category	no
<u>Time Horizon</u>	medium range (5-10 years)
<u>Cost Effectiveness</u>	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	high (large LP model)
- model, data and documentation updating	average

Contact: Mr. Frank Frederick
(713) 522-6800

TABLE V-10. EVALUATION OF THE RfF / RUSSELL MODEL

<u>Accuracy/Representativeness</u>.	
supply and demand factors included	supply only
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	yes
- mix of refinery types and sizes	no
demand side factors included:	
- mix of refinery outputs demanded	NA
- relative prices of refinery outputs	NA
- prices of substitutes	NA
- trends in output consumption and prices	NA
- incomes, demographic characteristics	NA
<u>Accuracy/Statistical Accuracy</u>.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	NA
- likelihood of incorrect estimators	NA
- missing variables	NA
<u>Availability</u>	Publicly available

TABLE V-10. EVALUATION OF THE RfF / RUSSELL MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	yes
- disaggregation by consumer category	no
Time Horizon	short/medium range (5 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	minimal
- installation costs	average/high (no support)
- documentation and user training	average/high (no support)
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average (no support)

Contact: Dr. Clifford S. Russell
(202) 328-5055

TABLE V-11. EVALUATION OF THE RICE/SMITH MODEL

Accuracy/Representativeness.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	no (one type of crude)
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	no
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	yes
- prices of substitutes	no
- trends in output consumption and prices	no
- incomes, demographic characteristics	yes
Accuracy/Statistical Accuracy.	
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	2% average (.30 - 33.33% range)
- RMSE	.15 average (.03 - .36 range)
- U	.002 - .227 range
econometric techniques:	
- estimation technique	OLS, GLS, 2SLS
- likelihood of incorrect estimators	Low, due to recursive model structure
- missing variables	Probable, due to small size of model
Availability	Publicly available

TABLE V-11. EVALUATION OF THE RICE/SMITH MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	no
- tracks emissions changes	no
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	yes
- disaggregation by consumer category	no
Time Horizon	medium range (5-10 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	low (publicly available)
- installation costs	low (small model)
- documentation and user training	low (small model)
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	low (small model)

Contact: Dr. Patricia Smith
Oak Ridge National Laboratory

TABLE V-12. EVALUATION OF THE ROLLINS MODEL

<u>Accuracy/Representativeness</u>.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes (limited)
- relative prices of refinery inputs	yes (limited)
- stationary source emission standards	no
- mix of refinery types and sizes	no
demand side factors included:	
- mix of refinery outputs demanded	yes (limited)
- relative prices of refinery outputs	yes (limited)
- prices of substitutes	no
- trends in output consumption and prices	no
- incomes, demographic characteristics	yes
<u>Accuracy/Statistical Accuracy</u>.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	2SLS
- likelihood of incorrect estimators	Low; Cochrane-Orcutt used to mimimize Autocorrelation
- missing variables	Likely, due to small model size
<u>Availability</u>	Publicly available

TABLE V-12. EVALUATION OF THE ROLLINS MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	no
- tracks emissions changes	no
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	yes (limited)
- disaggregation by consumer category	no
Time Horizon	short/medium range (5 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	None
- installation costs	low (model small)
- documentation and user training	low (model small)
recurring costs:	
- CPU time and set-up costs	low (model small)
- model, data and documentation updating	low (model small)

Contact: none

TABLE V-13. EVALUATION OF THE UNIVERSITY OF HOUSTON MODEL

Accuracy/Representativeness.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	yes
- mix of refinery types and sizes	yes
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	no
- prices of substitutes	no
- trends in output consumption and prices	yes
- incomes, demographic characteristics	yes
Accuracy/Statistical Accuracy.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	NA
- likelihood of incorrect estimators	NA
- missing variables	NA
Availability	Subject to negotiation

TABLE V-13. EVALUATION OF THE UNIVERSITY OF HOUSTON MODEL
(continued)

<u>Detail</u>	
high priority:	
- models various refinery configurations	yes
- tracks emissions changes	yes
lower priority:	
- disaggregation by region	yes (State of Texas)
- disaggregation by product mix	yes
- disaggregation by consumer category	no
<u>Time Horizon</u>	medium range (5-10 years)
<u>Cost Effectiveness</u>	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	high (large model)
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	high (large model)
- model, data and documentation updating	average

Contact: Dr. Russell G. Thompson
OPCON, Inc.
(713) 528-3158

TABLE V-14. EVALUATION OF THE UNIVERSITY OF TEXAS AT AUSTIN MODEL

<u>Accuracy/Representativeness</u>.	
supply and demand factors included	yes
supply side factors included:	
- mix of crude oil inputs	yes
- relative prices of refinery inputs	yes
- stationary source emission standards	no
- mix of refinery types and sizes	no (a single refinery)
demand side factors included:	
- mix of refinery outputs demanded	yes
- relative prices of refinery outputs	no
- prices of substitutes	no
- trends in output consumption and prices	yes
- incomes, demographic characteristics	no
<u>Accuracy/Statistical Accuracy</u>.	No information
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	NA
- U	NA
econometric techniques:	
- estimation technique	NA
- likelihood of incorrect estimators	NA
- missing variables	NA
<u>Availability</u>	Publicly available

TABLE V-14. EVALUATION OF THE UNIVERSITY OF TEXAS AT AUSTIN MODEL (continued)

Detail	
high priority:	
- models various refinery configurations	no
- tracks emissions changes	no
lower priority:	
- disaggregation by region	yes (limited)
- disaggregation by product mix	yes (limited)
- disaggregation by consumer category	no
Time Horizon	short/medium range (5 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	average (no support)
- installation costs	average (no support)
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	average/high (dynamic model, no support)
- model, data and documentation updating	average

Contact: none

TABLE V-15. EVALUATION OF THE VERLEGER/SHEEHAN MODEL

Accuracy/Representativeness.	
supply and demand factors included	demand only
supply side factors included:	
- mix of crude oil inputs	NA
- relative prices of refinery inputs	NA
- stationary source emission standards	NA
- mix of refinery types and sizes	NA
demand side factors included:	
- mix of refinery outputs demanded	no (gasoline only)
- relative prices of refinery outputs	no (gasoline only)
- prices of substitutes	yes
- trends in output consumption and prices	yes
- incomes, demographic characteristics	yes
Accuracy/Statistical Accuracy.	
ability to forecast outside sample period:	
- MAE	NA
- MAPE	NA
- RMSE	6% on average
- U	NA
performance over sample period:	
- MAE	NA
- MAPE	NA
- RMSE	6% on average
- U	NA
econometric techniques:	
- estimation technique	2SLS
- likelihood of incorrect estimators	Low, due to use of instrumental variables
- missing variables	NA (some prices missing)
Availability	Subject to negotiation

TABLE V-15. EVALUATION OF THE VERLEGER/SHEEHAN MODEL
(continued)

Detail	
high priority:	
- models various refinery configurations	no
- tracks emissions changes	no
lower priority:	
- disaggregation by region	no
- disaggregation by product mix	no
- disaggregation by consumer category	no
Time Horizon	medium range (5-10 years)
Cost Effectiveness	
initial costs:	
- model acquisition costs	to be negotiated
- installation costs	average
- documentation and user training	average
recurring costs:	
- CPU time and set-up costs	average
- model, data and documentation updating	average

Contact: Data Resources, Inc.
(617) 863-5100

TABLE V-16. SUMMARY OF MODEL EVALUATIONS

MODEL	...ACCURACY... D/S	STAT	AVAIL	....DETAIL.... EMISSIONS	OTHER
Adams	D&S	Good	S.T.Neg	Yes	Good
ADL	Supply	Fair	S.T.Neg	Yes	Good
Chou	D&S	NA	Public	No	Fair
Kennedy	D&S	NA	S.T.Neg	Yes	Poor
PACE	Supply	NA	S.T.Neg	Yes	Good
Pagoul.	D&S	NA	Public	No	Poor
REMS	Supply	NA	Public	Yes	Good
RPMS	Supply	NA	S.T.Neg	Yes	Good
RfF	Supply	NA	Public	Yes	Good
Rice	D&S	Good	Public	No	Poor
Rollins	D&S	NA	Public	No	Poor
U. Hous.	D&S	NA	S.T.Neg	Yes	Good
U.T.Aust.	D&S	NA	S.T.Neg	No	Fair
Ver/Shee	Demand	Good	S.T.Neg	No	Good

D&S: Demand and supply components are included
NA: Not available
S.T.Neg: Subject to negotiation
Good: Model rates above average in listed aspect
Fair: Model acceptable in listed aspect
Poor: Model rates below average in listed aspect

TABLE V-16. SUMMARY OF MODEL EVALUATIONS
(continued)

MODEL	TIME	.....COST EFFECTIVENESS.... INITIAL COST	RECURRING COST
Adams	M	Avg	Avg
ADL	M	Avg	Avg
Chou	M	Low	High
Kennedy	M	Avg	Avg/High
PACE	S/M	Avg/High	Avg
Pagoul.	M	Low	Avg
REMS	M	Low	Avg
RPMS	M	Avg/High	Avg/High
RfF	S/M	Low	Avg/High
Rice	M	Low	Avg
Rollins	S/M	Low	Low
U. Hous.	M	High	Avg/High
U.T. Aust.	S/M	Avg	High
Ver./Shee.	M	Avg	Avg

TIME: Time horizon of model
M: Medium-range time horizon
S/M: Short-to-medium-range time horizon

VI. RECOMMENDATIONS

The California Air Resources Board is looking for tools which can improve the ARB ability to evaluate candidate control measures and proposed changes in pollution emissions from California petroleum refineries. The analysis provided in this report is used as a basis for the following general recommendations:

Recommendation #1: Any economic model of the petroleum refinery industry used by the ARB needs to have:

- a supply (production) component,
- a demand (consumption) component, and
- a means for reaching demand and supply decisions for the petroleum industry as a whole.

An accurate evaluation must include both supply and demand considerations. The complex process options associated with refining allow for a wide range of production decisions. How refiners respond to proposed control measures can have a significant impact upon refinery prices and output mix and consumer demand. Conversely, changes in consumer demands patterns can strongly affect refinery activity levels, with subsequent impacts upon emissions. Neither supply nor demand comes "first;" consumption and production decisions are made simultaneously. Until both demand and supply considerations are included, and until these considerations are included for the industry as a whole, it will not be possible for the ARB to evaluate some of the impacts of candidate control measures. Although cost impacts can be estimated from a supply model, and sales of gasoline can be estimated from a demand model, a number of important variables (such as employment, investment and tax revenues) can only be assessed in a framework that considers demand and supply simultaneously.

Recommendation #2: The ARB should not try to develop its own supply component, but should try to acquire one of the existing models or modeling services.

The supply aspects of petroleum refinery modeling are the most well developed. Private firms have used linear programming techniques to allocate refinery inputs and outputs since the 1950's. Linear programming models include thousands of variables, and can simulate the behavior of almost any refinery. LP models have been used repeatedly by oil companies and by public agencies concerned with petroleum issues. Currently, there are a variety of supply models in use. Some are completely proprietary; because the ARB is seeking a refinery model for its own use, completely proprietary models are excluded from further consideration. However, there are a number of process models for which at least an "on-line" access is possible. There are also two models in the public domain: these models would be relatively cheap to acquire, although they could place a significant burden on ARB personnel when installation costs and data acquisition are considered.

Recommendation #3: The ARB should carefully evaluate how much use it would make of a petroleum refining model: this will determine whether the supply portion of the model is "purchased" or "leased."

For several of the privately available models, both a licensing option (in which a California-specific supply model is created for and sold to the ARB) and a leasing option (where only the use of such a supply model is granted, usually for a designated period of time) are possible. The "lease or buy" options are also available for the Department of Energy (REMS) model -- the ARB could acquire the REMS model and install it on ARB facilities, or the ARB could make arrangements to access the DOE computer and models as needed. (The latter option is currently used by the Environmental Protection Agency). If a model is purchased, higher initial costs are incurred than under a leasing or time-sharing agreement. However, if the model is used extensively, lease costs and telephone charges could exceed the cost of buying a model. The "breakeven" point for purchasing a supply model is at very regular usage levels: the ARB should consider purchasing or licensing a model if it expects to use the model at least monthly, and plans to analyze at least 10-20 cases per month. If this level of usage is not anticipated -- if the ARB will only do periodic studies, or will do studies occasionally throughout the year -- then leasing of a model, or a time-sharing arrangement with the REMS model, is recommended.

Recommendation #4: The ARB should also evaluate how much internal expertise it has -- and expects to have -- available: this will determine whether the ARB chooses a privately developed supply model or a publicly available one.

The supply models that are currently available require a sophisticated knowledge of petroleum refining processes and familiarity with linear programming techniques. The ARB must have access to individuals with petroleum engineering and process economics backgrounds, so that the characteristics of particular refineries are accurately included.

If such individuals are available at ARB, then the entire range of modeling options may be considered. At one extreme, the ARB could acquire the REMS model from the Department of Energy and undertake all installation and usage activities itself. The initial external costs to the ARB of such a "go it alone" option would be minor, including items such as computer tapes on which to transmit the model. However, if linear programming or petroleum refining skills at ARB are scarce (or are expected to be scarce in the future), acquisition of the REMS model becomes risky -- since DOE provides no support along with the model, ARB staff would have responsibility for installing the model, learning to use it, and expanding it to include California-specific data. At the other extreme of choices, the ARB could request "on-line" access to one of the commercially available systems. Initial external costs would be higher, but the training, documentation and support services might be well worth the added cost.

Recommendation #5: The demand component, and the methodology for reaching demand and supply decisions for the industry as a whole, will have to be developed by the ARB.

The demand component of petroleum refining models is not as well developed as the supply component. Most of the existing models take demand estimates as given. Usually, these demand estimates are obtained from one of the major economic forecasting companies -- Data Resources Incorporated, Wharton Economic Forecasting Associates, Chase Econometrics, etc. -- or from data developed by public agencies such as the Federal Energy Administration.

Simultaneous, industry-wide determination of demand and supply is the least developed aspect of petroleum modeling. Many of the models are iterative: "reasonable" demand estimates are made, and used in the LP model to derive initial costs and output combinations. The results are used to revise the demand estimates, and a second round of modeling begins. Some models are block recursive -- subsets of the variables are determined simultaneously. In the past, use of simultaneous models was limited by computer capacity. As computing capabilities increase, so do the possibilities for simultaneous, industry-wide estimation of policy variables.

California-specific models that include supply, demand and general equilibrium considerations do not currently exist. Models that do include all three components are relatively aggregate, national ones. A state-specific model would have to account for relatively large interregional flows of refinery inputs and outputs as well as people, jobs, revenues, and incomes. This will require research that has not yet been undertaken elsewhere.

<u>Recommendation #6</u>: A petroleum refinery modeling capability should be acquired in stages. A supply component should be acquired first, followed by a demand component and industry-wide estimation capabilities.

This recommendation may sound like it conflicts with the first recommendation, but it does not. Eventually, a model of environmental policy in the petroleum refining industry should include production and consumption considerations, and include these considerations at an industry-wide and state-wide level, so that employment and revenue issues can also be evaluated. However, the best way to guarantee that such a model is never developed is to try and build it all at once, creating a heavy burden on ARB resources (both people and dollars) and increasing the number of places in which something can go wrong. If the model is developed in stages, the ARB can focus its attention more effectively on each component, and can have an opportunity to assess the value of each portion of the model as it is developed.

In the remainder of this report, specific tasks for building an economic model of the petroleum refining industry are outlined. Where possible, alternative options for undertaking a task are given, so that the option most suitable to ARB resources and needs may be chosen. The tasks are organized so that usable information is generated at the completion of each task: the ARB will not have to finish a huge modeling effort before results become available, although more types of questions can be answered as more tasks are completed.

<u>Task 1: Developing a Supply Component</u>

The supply component for an economic model of the petroleum refining industry will take the largest amount of ARB resources. However, once a supply model is acquired, the ARB can evaluate the impact of candidate control measures on refinery output mix and costs.

Obtaining and using a petroleum refining supply model requires the following categories of items:

(1) Computer capabilities

- access to a mainframe computer (such as the IBM S/370 Model 3033)

(2) A refinery model

- access to a refinery modeling system (such as PMS, REMS, or RPMS)

(3) Software (programs which can run the refinery model)

- problem-solving software, to solve the linear programming problem (examples are IBM's Mathematical Programming System -- MPS X -- and MPS III, available through Ketron, Inc.)

- software for generating the matrix of information and for report writing (examples of such programs are OMNI and MAGEN, both available through Haverly, Inc.)

(4) Data

- petroleum refining data (information on costs characteristics of the refinery technologies, inputs and outputs)

- emissions characterizations (information on the quantities and mix of pollution residuals associated with each type of refining process and input)

(5) Installation and Verification

- initial installation (getting the refinery model set up on the computer)

- verification (running the model for a known configuration)

- training

(6) Recurring costs

- modifications (changing the characteristics of refinery inputs, technical configuration, etc.)

- computer operation time

Item (1) and the first listing under Item (3) are not discussed further in the task outlines that follow, since the ARB has access to an IBM mainframe computer with MPS software on it. The items which need to be considered further are:

- the refinery modeling system
- matrix generation software
- refinery production data
- emissions characterization

- installation
- verification
- training
- modifications
- computer operation time

Each of these items is discussed in the options which are outlined below.

The ARB has two main options in acquisition of a supply model: it can obtain a publicly available model, or it can use a supply model generated from a private source (such as Bonner and Moore or PACE). Within each of these two main options, there are two sub-options: regardless of whether the ARB goes with a private or public model, the model may be purchased (licensed), or it may be used as needed (leased).

Of the publicly available supply models, the REMS model is preferable: it is receiving continuing support, whereas models such as the one by Russell were developed for specific studies and are no longer being updated and modified. Whether REMS is acquired for use on the ARB system, or time-sharing arrangements are made with DOE, is dependent upon the amount of use ARB will make of petroleum refinery modeling.

If ARB acquires the REMS model, the following costs and activities are to be expected:

- the refinery modeling system: the REMS model may be obtained by sending a letter requesting the model along with a blank magnetic tape to the Department of Energy.
- matrix generation software: REMS currently uses OMNI, which is available from Haverly, Inc. in New Jersey (telephone 201-627-1424). OMNI is preferable to alternatives such as MAGEN (since MAGEN is no longer supported). However, the software is a significant investment: OMNI can be purchased for $30,000 or it can be leased for approximately $1,000/month.
- refinery production data: information on petroleum flows and refinery operations can be obtained from the Department of Energy: DOE PAD District information is based upon state data. For state agencies such as ARB, the information is available free of charge.
- emissions characterization: this step requires some research and refinery engineering know-how, since emissions are usually not a simple correlation with refining output or technology. An outside organization, such as Bonner and Moore, Pace, or Sobotka, could do such a characterization for approximately $5,000 (the range would be about $3-10,000, depending upon how specific the refining areas and technology descriptions need to be).
- installation: Terrence Higgins is now at Sobotka, but was at DOE when REMS was developed and assisted EPA in its use of the REMS model. Higgins estimates that his firm could complete installation on the ARB computer and train "systems" people in the use of REMS for about $6,000, including travel. There are probably other organizations that could also help ARB install the model, but Sobotka has worked with this model in the past.
- verification: a small "dry run," using the REMS model on a known configuration, will help validate the model and train ARB

personnel in the use of REMS. Simple verification runs could be done in about 2 weeks; if an outside organization is used to evaluate and verify the model, it would cost around $7,000 ($5-10,000, depending on the amount of detail in the case study).

- training: since verification is an excellent opportunity for training, ARB personnel should be involved in the verification task, whether or not outside help is also used. Some additional training may also be helpful: Sobotka would be the place to go for this help, and it would probably cost around $3,000.
- modifications: REMS is a fairly flexible modeling system; most modifications can be done with the system as it stands.
- computer operation time: these costs are minimal ($10-15), but are incurred each time a case is run on the computer.

If the ARB chooses to use REMS on DOE facilities, the costs and activities are as follows:

- the refinery modeling system: already available at DOE.
- matrix generation software: already available at DOE.
- refinery production data: already available at DOE.
- emissions characterization: still needs to be done (see above).
- installation: no longer applicable.
- verification: no longer applicable.
- training: still needed (see above).
- modifications: see above.
- computer operation time: in addition to the recurring costs identified above, telephone charges for access to the DOE computer in Washington DC must also be added.

This is the option used by the Environmental Protection Administration; EPA transferred some "up front" money to DOE for this modeling effort, and the funds have been used up over time to help support the model. The exact details of an ARB-DOE time-sharing arrangement would have to be finalized in negotiations between the Air Resources Board and DOE.

As an alternative to the REMS model, ARB could license or lease a model from a private company engaged in petroleum refinery modeling. If ARB preferred to buy (obtain an exclusive license for) a supply model, a "package deal" is usually developed, in which the modeling system, matrix generating software, use of a refinery data library, installation, modifications, verification, and extensive training are included. ARB would still have to do an emission characterization (although that could also be one of the items requested from the private firm) and would still incur computer operations costs. Such licensing agreements would cost between $50,000 and $150,000, depending on the level of detail the ARB expects to include. Leasing arrangements are also possible, and range from $15,000 to $50,000 per year, depending again on the level of complexity.

If a private supply model is preferred, the following organizations are possibilities:

- Arthur D. Little, Inc. [The ADL Model]
- Bonner and Moore Management Science, Inc. [The RPMS System]
- Operational Economics, Inc. (OPCON) [The University of Houston Model]
- The Pace Company [The PMS Model]

Although Bonner and Moore has done more work with the state of California, there is not a "best" candidate: which one is chosen would depend on costs and services supplied along with the model. Each organization is described in Appendix B of this report.

Currently, the REMS modeling option appears to be the most suitable for ARB needs. This conclusion is based upon two facts and one observation. Fact 1: the REMS refinery modeling system is available to the ARB free of charge. Fact 2: public agencies, such as the ARB, have access to the state data available in the DOE/EPA database. The observation (and perhaps the most important reason for reaching the conclusion noted above): some ARB employees have the computer skills and modeling knowledge necessary for understanding and using economic models of the petroleum refinery industry. <u>If this situation is expected to change</u> -- in particular, if the experienced individuals are first on the cutback list or likely to job-hop -- then the ARB should instead rely upon private firms for supply modeling capabilities.

<u>Task 2: Developing a Demand Component</u>

The success (or problems) which the ARB has with obtaining a supply model will have implications for the remaining two tasks. If ARB finds that it makes little use of a petroleum refining supply model, it may decide not to devote funds toward development of a demand module or exploration of industry-wide assessment techniques. Alternatively, extensive use of a supply model would give ARB a better idea of the types of information it needed to generate in the next two tasks.

However, the development of a demand module is necessary for evaluation of environmental policy options, since supply aspects are "only half the story." The amount of petroleum refining activity depends not only upon the cost structure and production techniques facing refiners, but also upon the utilization of refined products by consumers and by other industries. An understanding of the factors which encourage or discourage refined petroleum demand is crucial to an ability to forecast refined product usage and the associated environmental consequences.

Previous studies of demand have found that purchases of a product depend upon the following kinds of factors:

<u>current income</u> -- this is included as a measure of spending power,
<u>current prices</u> -- the price of the product, the prices of items which are used in conjunction with the product (such as the cost of operating a car) and the prices of alternatives are usually included, since these indicate the relative costliness of the product,

the stock of durable goods using the product -- variables such as the number of automobiles or jets provide an indication of overall demand levels,

characteristics of of items which use the product -- fuel efficiency, weight, and the presence of air conditioning on a car influence use of refined petroleum products on a per-car basis,

demographic characteristics -- population measures such as the number of licensed drivers or indices of urban "sprawl" can indicate total demand levels, while characteristics such as the number of individuals or children per household provide clues to the kind of cars which are driven, and

other variables -- "habit" is often an important variable; individual driving patterns rarely change overnight.

Many of these variables overlap: the number of licensed drivers and the number of licensed automobiles could both be used to measure total levels of demand for gasoline. Thus, part of the effort associated with the demand modeling task will be choosing among alternative measures of demand, or using economic and statistical tools to develop indices of demand variables.

The demand modeling task should segment refinery demand into at least two parts: demand for gasoline (which represents the majority of refinery output in the state of California) and the demand for other refinery products. Demand in the gasoline segment is for final use by consumers, while demand in the other segment (for products such as asphalt) tends to be industrial demand, and the refined products are used as inputs to construction and to other manufacturing processes. While both segments will depend upon the factors listed above, the most appropriate measures may differ between the two segments. (As an example, the prices of diesel fuel and public transportation might be included as alternatives in the gasoline market, whereas the prices of cement and construction labor might be more appropriate prices to consider in the asphalt market).

Most of the previous modeling efforts associated with refinery product demand have emphasized gasoline demand; ARB demand models will be able to draw upon the work of Adams and Griffin, Data Resources Inc., Kennedy, Rice, Sweeney, and Verleger and Sheehan. However, since most of these studies emphasized world or national demand, the ARB modeling task will need to determine how many of these national estimates are appropriate to the State of California, since California pollution control regulations and vehicle use patterns are different from those of the rest of the United States. These models tend to divide demand into two components: a short term demand (where consumers are "stuck" with whatever brand of automobile they own, but can vary the number of miles driven), and a long term demand which depends on the type of car they choose to own and how they choose to drive. Gasoline usage becomes more flexible the longer the time horizon, since decisions about what to drive as well as how much to drive become possible.

Relatively little analysis has been done on non-gasoline demand for refinery output. Demand analyses for some products may be found in Adams and Griffin, DRI, Kennedy and Rice, although the analysis is again at the aggregate level (for the world or for the United States). Since the non-gasoline segment reflects industrial demands, production models (models in which the refined product is merely one input, and the user chooses as much of the refined product and any other inputs as will maximize producer profits) are most appropriate.

Because of the interdependence among variables in the model, the resulting equations can NOT be estimated separately. Several simultaneous estimation techniques -- Two Stage Least Squares (2SLS), Instrumental Variables (IV), error component techniques, and three stage least squares (3SLS) are all possible estimation methods, but Ordinary Least Squares (OLS) is not. Which of the estimation methods is actually chosen depends upon the form of the model and the types of variables which are included. Lagged variables and quarterly or monthly data create special estimation problems; prospective model-builders will need to indicate what problems they anticipate and how they intend to handle the problems if they include such variables.

As with the supply model, obtaining and using a demand model of the petroleum refining industry requires the following categories of items:

(1) Computer capabilities
(2) A demand model
(3) Software (programs which can run the model)
(4) Data (information on refinery output prices, demand for each type of refinery product, consumer income, the stock of petroleum-using capital goods, consumer utilization of those capital goods, etc.)
(5) Installation and Verification (getting the model set up on the computer and producing reasonable results for known situations)
(6) Recurring costs

Item (1) is not discussed, since the ARB has access to an IBM mainframe computer. Item (3) is also not discussed; the software would need to be compatible with existing or proposed ARB software, but will not require extensive acquisitions of software as the supply model will. The remainder of the discussion of this task divides the effort into two main categories; the development of a demand model (including installation), and the acquisition of California-specific data for the demand model. These need not be separate subtasks, although the talents needed for each subtask are slightly different.

A demand model would need to indicate consumer response to changing product prices, incomes, and demographic characteristics. The model needs to distinguish between the demand for gasoline and the demand for other petroleum products. In the gasoline portion of the model, distinctions between short-run demands (where the stock of automobiles is fixed, but usage of the automobile can vary) and long-run demand (where usage and stock are flexible) would need to be made. Nationwide models of gasoline demand have been developed: although these efforts provide useful background, regional versions of these models would be required. For the non-gasoline markets, intermediate-goods modeling would need to be included.

Several organizations and individuals have the ability to do demand modeling. To obtain a demand model, the ARB would let a contract for about $50,000 ($30,000-$100,000, depending upon the level of detail required). The Request for Proposals (RFP) would need to indicate the types of variables of interest and existing and anticipated software at ARB. (The exact measures used in the demand model, particularly those explaining automobile usage, should not be specified in advance -- a little "casual empiricism" followed up by comparisons among competing measures would be most useful). The RFP should also request that the respondent compare the output of the demand model with historic information or with the output from other economic models, and that the model be installed on the ARB system and be clearly documented.

Data acquisition could probably also be requested in the RFP. Price data for petroleum products is available from sources such as Petroleum Marketing Monthly and the Monthly Energy Review. Gasoline sales data is available by state by month from the American Petroleum Institute and from the Federal Highway Administration. Data on population, income, and price deflators are available on a state-by-state basis from the Commerce Department's Bureau of Economic Analysis. Other variables are available from a variety of sources -- the Department of Motor Vehicles has information on licensed drivers, the Environmental Protection Administration develops estimates of fuel efficiency. Much of this data has already been pulled together by economic research services such as Data Resources Inc., Wharton Economic Forecasting Associates, and Chase Econometrics -- it might be easier for the ARB to subscribe to one of these services (if it doesn't already) than to acquire and periodically update the information. However, public agencies such as the ARB have access to state data from DOE, EPA and the Census Bureau free of charge. Thus, it would probably be best for the ARB to request information on those variables already available on a state-by-state basis from national agencies such as DOE, and to request information on other demand variables (automobile utilization rates, etc.) be developed or acquired by the contractor developing the demand model.

Task 3: Developing an Industry-Wide Modeling Capability

The simultaneity and general equilibrium issue is more speculative: if it successfully accomplished, it would provide an ability to assess investment, employment, and revenue effects of ARB control measures. It would also greatly increase the computer time needed to assess each case.

For now, one or two small research contracts (of about $25,000) could be given to explore alternative econometric methodologies that combine supply and demand components. The Request for Proposals would require simultaneous determination of particular demand and supply variables (to be specified by the ARB, but likely to include demands for major petroleum products). Models by Chou, Kennedy, Rice and the University of Texas at Austin have begun to explore simultaneous estimation methods. However, these models were for the United States as a whole or for the Texas region; they also used a variety of econometric methods.

A general equilibrium approach (which could more directly address the long-range employment impacts of ARB actions) would be a much larger research effort, and further in the future. Before embarking on a large simultaneous modeling effort, the ARB should consider waiting for the results of some general equilibrium model development that is being done at EPA. (A word of warning: the EPA effort is far behind schedule).

APPENDIX A

ANNOTATED LITERATURE

This appendix summarizes the published sources of information on economic models of the petroleum refining industry. The appendix is divided into two parts: Part I includes all relevant documents that were referenced during a formal literature search, and Part II contains all references that were cited in these documents or were provided by individuals or organizations contacted by telephone.

For each document, the following information is given:

<u>Entry Number</u>. (This number is applicable to Part I only). The citation number and source database within the Lockheed Dialog system are provided for ease of library retrieval.

<u>Title</u>.

<u>Author(s)</u>.

<u>Affiliation</u>. Organization to which the authors belonged are listed.

<u>Sponsor</u>. The principal funding agency is indicated.

<u>Source</u>. Either the publication in which the document appeared or the organization from which the document may be obtained is listed.

<u>Date</u>.

<u>Abstract</u>. A brief summary of the document is given.

I. References Obtained from the Lockheed Dialog (TM) Literature Search

Entry Number: 108364 (Energyline)
Title: An Integrated Industry Model of Petroleum Refining, Electric Power, and Chemicals Industries for Costing Pollution Control and Estimating Energy Prices
Author: James A. Calloway, Russell G. Thompson
Affiliation: University of Houston (Houston, Texas)
Sponsor: --
Source: Engineering and Process Economics, Volume 1, Number 3 (September 1976), pp. 199-217.
Date: September 1976
Abstract: Examples of how technical information may be synthesized into a comprehensive economic model are given to evaluate the industry cost, market price, and economic impact of restrictive waste discharge standards for the petroleum refining, electric power, and important chemical industries. Results show industry costs, where price inflation is ignored, of increasingly restrictive standards for major air and water pollutants. How the industry model has been interfaced with resource supply and end product demand models to estimate market price effects is described. The market results are then used to determine the economic impact of different effluent standards.

Entry Number: 118092 (Energyline)
Title: A Review of Energy Models
Author: International Institute for Applied Systems Analysis (IIASA)
Affiliation: same
Sponsor: same
Source: IIASA; Report No. RR-78-12
Date: July 1978
Abstract: Fourteen energy models are reviewed. The models are classified according to the numbers and kinds of fuel considered, national vs. international application, and characterization of an energy system only or of a system linking energy and economics. The models have been applied to the mining industry, Canadian natural gas, The Belgian refining industry, power station installation policies, U. S. coal supplies, and national energy plans for the U. S., Mexico, Sweden, New Zealand, and other countries. Included in each model are: the subject, goal, system description, time and space application, modeling techniques used, input data required (operational, physical, technical, resource, and economic), and individuals involved in developing and using these models.

Entry Number: 121385 (Energyline)
Title: 1980 Motor Gasoline Supply and Demand
Author: Ercan Tukenmez, Richard Farmer, Hilda McDaniel, Charles Everett, Howard Walton
Affiliation: DOE (Office of Energy Source and Use Analysis)
Sponsor: DOE
Source: DOE Report DOE/EIA-0102/32
Date: December 1978
Abstract: The study used two analytical tools to project motor gasoline supply and demand through 1980. The short-term petroleum product demand forecasting model estimated motor gasoline use for 1980; the refinery and petrochemical modeling system evaluated the capability of domestic refineries to supply the projected demand levels. At projected levels, the refinery industry would have to take actions to increase supplies, particularly to offset the effects of the EPA phase-down of octane-increasing lead additives. Several options available to the petroleum industry to extend supplies are described.

Entry Number: 131703 (Energyline)
Title: U.S. Oil Geography in 1990: Scenarios and Implications for Economic Policy
Author: E. V. Niemeyer and J. W. McKie
Affiliation: University of Texas
Sponsor: --
Source: NTIS; Report No. UT/CES-PS-5
Date: October 1978
Abstract: The geography of crude oil movements, oil refining location, and shipment of refined products to markets in the U. S. has been changing at an accelerating rate since 1970. Several possible scenarios of future petroleum development are analyzed. Factors important in determining the economic geography of the domestic oil industry are identified.

Entry Number: 131963 (Energyline)
Title: Costs and Benefits of a Protective Tariff on Refined Petroleum Products After Crude Oil Decontrol
Author: Stephen E. McGregor
Affiliation: DOE
Sponsor: DOE
Source: DOE Technical Information Center, Oak Ridge, TN
Date: January 31, 1980
Abstract: National benefits and costs of a product import tariff aimed at providing a reliable supply of refined petroleum products are assessed through three policy options: (1) unrestricted free trade; (2) a $1/bbl tariff on all refined imports; (2) a $2/bbl tariff. A U.S. refining industry computer model projected the levels of domestic refiner utilization and imports under the three scenarios. The computer model and other data were used to determine the impacts of tariffs on real resource costs to the U.S. economy, consumer prices, GNP, employment, inflation, and the balance of payments.

Entry Number: 213229 (NTIS)
Title: Future Water Demands: The Impacts of Technological Change, Public Policies, and Changing Market Conditions on the Water Use Patterns of Selected Sectors of the United States Economy: 1970-1990
Author: Charles W. Howe, Clifford S. Russell, Robert A. Young, William J. Vaughan
Affiliation: Resources for the Future, Inc. (Washington, DC)
Sponsor: --
Source: RfF Report No. NWC-EES-71-001 (NTIS Code PB-197 877)
Date: March 1971
Abstract: The study analyzes the the impacts of likely market trends, alternative public policies, and technological change on the water use patterns of some of the major water-using or polluting industries. The sectors included were urban (residential), three representative industries in the industrial sector (thermal electric power, beet sugar refining, petroleum refining), and agricultural. Findings for the individual sectoral studies are summarized.

Entry Number: 254048 (DOE Energy Database)
Title: The Impact of Lead Additive Regulations on the Petroleum Refining Industry (Volume 1: Project Summary)
Author: N. Godley, S. G. Johnson, W. A. Johnson, J. R. Kittrell, T. G. Pollitt
Affiliation: Arthur D. Little, Inc.
Sponsor: Environmental Protection Agency
Source: NTIS; Report Number PB-260411
Date: May 1976
Abstract: The study assesses the impact on the U. S. petroleum refining industry of two EPA regulations promulgated to control the level of lead additives in motor gasoline. The first regulation requires the availability of low-octane, unleaded gasoline for vehicles equipped with lead-sensitive catalytic converters. For health reasons, the second regulation requires a gradual phase-down of the lead content of the total gasoline pool. Computer models representative of specific refineries in six geographical regions of the U. S. were developed as the basis for determining the impact on the existing refinery industry. These models were utilized to assess investment and energy requirements to meet each lead regulation.

Entry Number: 254050 and 254051 (DOE Energy Database)
Title: The Impact of Producing Low-Sulfur, Unleaded Motor Gasoline on the Petroleum Refining Industry (Volume 1: Project Summary; Volume 2: Detailed Study Results)
Author: N. Godley, S. G. Johnson, W. A. Johnson, J. R. Kittrell, T. G. Pollitt
Affiliation: Arthur D. Little, Inc.
Sponsor: Environmental Protection Agency
Source: NTIS - Report Number PB-260587 and PB-260588
Date: May 1976
Abstract: The study assesses the impact on the U. S. petroleum refining industry of possible EPA regulations restricting the sulfur content of unleaded gasoline. Sulfur levels of 100 ppm and 50 ppm are considered. Computer models representative of specific refineries in six geographical regions of the U. S. were developed as the basis for determining the impact on the existing refinery industry. New refinery construction during the

period of analysis (1975-1985) was considered by development of separate computer models rather than the expansion of existing refineries. These models were utilized to assess investment, energy requirements and incremental costs to manufacture low-sulfur unleaded gasoline. Sensitivity analyses examined the effect of variations in key assumptions on the results of the study.

Entry Number: 255434 (DOE Energy Database)
Title: Economic Analysis of Environment and Energy in the Petroleum Refining, Electric Power, and Chemical Industries
Author: R. G. Thompson et al
Affiliation: University of Houston
Sponsor: --
Source: Proceedings of the 1976 Summer Computer Simulation Conference, Washington DC, July 12, 1976. Document available through DOE/Oak Ridge National Laboratories (Document No. CONF-760703, pp. 788-794).
Date: 1976
Abstract: This study contrasted regulated and competitive use of fuel oil and natural gas in their effects on the market-clearing price of natural gas, the end use of energy products, and the production costs of heavy industry in 1985. Solutions were computed for different supply responses to price to show the effects of uncertainties in forecasting supplies of domestic petroleum. Results of the modeling study showed that: (1) prohibition of petroleum fuel use in new electric power generation facilities significantly moderated the economic costs of attaining clean water and clean air; and (2) large uncertainties in future indigenous supplies of crude oil and natural gas in the United States did not change the character of the modeling results.

Entry Number: 293568 (DOE Energy Database)
Title: Tax Policy and Energy Conservation
Author: E. A. Hudson, D. W. Jorgenson
Affiliation: MIT
Sponsor: --
Source: Chapter 2 of Econometric Studies of U. S. Energy Policy, edited by D. W. Jorgenson (Amsterdam: North-Holland Publishing Company, 1976)
Date: 1976
Abstract: This paper integrates econometric modeling and input-output analysis and incorporates a new methodology for assessing the impact of economic policy on supply. The first component of the framework for energy policy analysis is an econometric model of inter-industry transactions for nine domestic industries. The business sector of the U.S. economy has been subdivided into nine industrial groups for detailed analysis. The inter-industry model includes a model of demand for inputs and supply of output for each of the industrial sectors. The model is closed by balance equations between demand and supply for the products of each of the nine sectors. The model can be used to study the impact of specific policy changes on energy demand and supply, energy price and cost, energy imports and exports, and U.S. economic growth.

Entry Number: 293609 (DOE Energy Database)
Title: World Oil Model
Author: M. Kennedy
Affiliation: MIT
Sponsor: --
Source: Chapter 3 of Econometric Studies of U. S. Energy Policy, edited by D. W. Jorgenson (Amsterdam: North-Holland Publishing Company, 1976)
Date: 1976
Abstract: This essay describes the structure of an economic model of the world oil market, and presents some results from it for use in forecasting and policy simulation. The model is a regional multi-market general equilibrium model of the international oil industry. It consists of four segments: crude production, transportation, refining, and consumption of products. Commodities are distinguished by both physical characteristics (with crude oil and the various refined products explicitly represented) and location. In each region the demand for refined products and the supply of crude oil are functions of price, and the model determines physical flows and prices simultaneously.

Entry Number: 315715 (DOE Energy Database)
Title: Projected Availability of Motor Gasoline and Distillate Fuels 1975-1985
Author: Bonner and Moore Associates, Inc.
Affiliation: same
Sponsor: United States Army Coating and Chemical Laboratory.
Source: NTIS; Report No. AD-775859; RGH-042
Date: January 15 1974
Abstract: Reports on a research project involving the preparation of forecasts for raw materials availability and product demands for the U. S. refining industry through 1985 and the construction of a mathematical model for the industry. The model was constructed for use in forecasting industry investment and operating characteristics which will be necessary to meet product demands. A linear programming model form was used in conjunction with a special study methodology which was found to be effective in similar work.

Entry Number: 348811 (DOE Energy Database)
Title: Econometric Model of the Petroleum Industry
Author: P. L. Rice, V. K. Smith
Affiliation: Oak Ridge National Laboratory, Oak Ridge, TN
Sponsor: --
Source: The Journal of Econometrics, Volume 6, Number 3 (November, 1977), pp. 263-287.
Date: 1976
Abstract: Paper describes a forty-two nonlinear equation model of the U.S. petroleum industry estimated over the 1946-1973 period. The model specifies refinery outputs and prices as being determined by market forces while the domestic output of crude oil is determined in a block-recursive segment estimated with nonlinear two-stage least squares adjusted to reflect the implications of autocorrelation for those equations where it appears to be a problem. A multi-period sample simulation, together with forecasts for 1974 and 1975 are used to evaluate the model's performance.

Entry Number: 374185 (DOE Energy Database)
Title: Market-Oriented World Petroleum Model
Author: W. L. Chou
Affiliation: University of Illinois, Urbana
Sponsor: PhD Thesis
Source: University Microfilms, Order No. 77-26, 648.
Date: 1977
Abstract: Develops a quadratic programming (QP) model of world energy (petroleum) that reflects world price and quantity interactions. The spatial equilibrium model of Takayama and Judge is used as the basis of the study. The quasi-welfare objective function (in quadratic form) is maximized subject to a large number of constraints involving crude oil availability, refinery process capacity utilization, production-distribution of final products, distribution and regional demand constraints, and the non-negativity of all variables involved. There are six refinery-consumption regions, fourteen types of crude oil and nine refined products considered in the study. The model generates the quantities of optimum consumption and production of crude oil and its products in different regions, the optimum volume and flow of each refined product, and equilibrium market prices of various refined products and crudes.

Entry Number: 380417 (DOE Energy Database)
Title: Econometric Model of the Petroleum Industry
Author: P. L. Rice
Affiliation: SUNY Binghamton
Sponsor: PhD Thesis
Source: University Microfilms, Order No. 76-16, 865.
Date: 1976
Abstract: The study models the petroleum industry to provide a vehicle for analyzing the effects of different policy options on prices, reserve and production quantities, and associated demands for crude oil and its refined products. The model specifies refinery outputs and prices as being determined by market forces while the domestic output of crude oil is determined in a block-recursive segment estimated with nonlinear two-stage least squares adjusted to reflect the implications of autocorrelation for those equations where it appears to be a problem. A multi-period sample simulation, together with forecasts for 1974 and 1975 are used to evaluate the model's performance. The model is used to examine the implications of the elimination of oil depletion allowances and further price increases by OPEC.

Entry Number: 403362 (DOE Energy Database)
Title: Cost of Energy and a Clean Environment
Author: R. G. Thompson, J. A. Calloway, L. Nawalanic (editors)
Affiliation: --
Sponsor: --
Source: Gulf Publishing Company, Houston, TX (Book)
Date: 1978
Abstract: An economic framework is constructed to synthesize relevant technical information into a computer-based model to identify key decision variables and to measure the resource, environmental, and economic consequences of changes in these variables. The model focuses on the petroleum refining,

electric power, and basic chemicals industries, and evaluates the economic consequences of of imposing restrictive effluent standards, energy pricing regulations, and end-use fuel prohibitions for the fossil energy sector of the economy in 1985.

Entry Number: 446628 (NTIS)
Title: Production of Low-Sulfur Gasoline
Author: W. F. Hoot
Affiliation: M. W. Kellogg Co.
Sponsor: National Environmental Research Center
Source: NTIS; PB-240 558/7
Date: July 1974
Abstract: The use of catalytic converters is intended to control carbon monoxide and hydrocarbon emissions. However, the catalysts convert some of the sulfur in gasoline into sulfuric acid mist in the exhaust. The purpose of this study was to determine the impact on oil refineries to produce unleaded, low-sulfur gasolines and also to desulfurize all gasolines produced for United States sales.

Entry Number: 474706 (DOE Energy Database)
Title: Construction of a Multiregional Input-Output Model for the Pacific Northwest
Author: John R. Wilkins
Affiliation: Economics, Statistics, and Cooperatives Service (Washington, DC)
Sponsor: Pacific Northwest Regional Commission (Washington), Northwest Energy Policy Project (Oregon)
Source: NTIS (Report No. PB-282431)
Date: 1978
Abstract: The report describes construction of a multiregional input-output model for Washington, Oregon, and Idaho. Each state portion of the model has twenty-six sectors based on SIC definitions. Major energy producing sectors included in the model are petroleum refining, electric utilities, and natural gas utilities. Major energy consuming sectors are food processing, lumber and wood, pulp and paper, chemicals, aluminum, transportation, trade and services. The model was projected to 1985 to facilitate analysis of projected economic scenarios.

Entry Number: 474989 (DOE Energy Database)
Title: Prices, Inventories, and Capacity: A Theoretical-Empirical Study of the Downstream Petroleum Industry
Author: J. B. Rollins
Affiliation: Texas A&M University
Sponsor: PhD Thesis
Source: University Microfilms, Order No. 79-01, 003.
Date: 1978
Abstract: This study develops a theory of the multiproduct petroleum firm, which holds inventories of products under conditions of stochastic demand and supply. Under certain conditions, such as fixed output proportions, the theoretical model reaches certain conclusions regarding product demand, product prices, product inventories, and refining capacity. The theoretical model provides the basis for an econometric model of the downstream (refining and product distribution) operations of the petroleum

industry. The empirical results demonstrate the importance of inventories and capacity, as well as the money prices of products, in both demand and production decisions.

Entry Number: 526218 and 526219 (NTIS)
Title: The Impact of SOx Emissions Control on the Petroleum Refining Industry (Volume 1: Study Results and Planning Assumptions; Volume 2: Detailed Study Results)
Author: James R. Kittrell, Nigel Godley
Affiliation: Arthur D. Little, Inc.
Sponsor: Industrial Environmental Research Laboratory (Research Triangle Park, NC)
Source: NTIS; Report No. EPA-600/2-76-161a and b
Date: June 1976
Abstract: The study assesses the impact on the U. S. petroleum refining industry of a possible EPA regulation limiting the level of gaseous refinery sulfur oxide emissions. Computer models representative of specific refineries in six geographical regions of the U. S. were developed as the basis for determining the impact on the existing refinery industry. New refinery construction during the period of analysis (1975-1985) was considered by development of separate computer models rather than the expansion of existing refineries. Control of refinery SOx emissions from both existing and new refineries was defined for the purposes of the study by maximum sulfur levels on refinery fuel and on fluid catalytic cracking unit feedstock and by increased sulfur recovery in the Claus plant. These models were utilized to assess investment, energy requirements and incremental costs to comply with the regulation. Sensitivity analyses examined the effect of variations in key assumptions on the results of the study.

Entry Number: 532695 (Compendex)
Title: Diffusion of Environment-Saving Technological Change $EM DASH$ A Petroleum Refining Case Study
Author: Hyder Lakhani
Affiliation: Maryland Dept. of Economic and Community Development
Sponsor: --
Source: Technological Forecasting and Social Change, Volume 7, Number 1 (1975), pp. 33-55.
Date: 1975
Abstract: Paper attempts to model a dynamic relationship, brought about by environment-saving technological changes over time, between output and water pollution. The improvement in environmental quality is studied in terms of adoption of relatively environment-saving processes in the petroleum refining industry. Social desirability of substituting the various options is examined in terms of social benefit-cost analysis.

Entry Number: 533689 (NTIS)
Title: Impact on Air Quality of Alternate Strategies for the Production, Distribution, and Utilization of Energy in Texas, 1975-2000.
Author: B. Stewart
Affiliation: Texas Air Control Board, Austin
Sponsor: Energy Research and Development Administration
Source: NTIS; Report No. NSF-RA-N-74-234
Date: January 1975
Abstract: As natural gas costs increase, the use of alternative fuels is expected to result in increased emissions to the Texas atmosphere of air pollutants such as sulfur dioxide and particulate matter. The application of pollution control technology is costly and should not be required unless necessary to protect the population from exposure to unacceptable levels of pollution. The purpose of this study is to examine possible energy growth patterns and translate this growth into resulting effects on the Texas environment. Three growth patterns were chosen, and air pollutant emissions were predicted for all growth projections. The implications for pollution levels are summarized.

Entry Number: 551489 (Compendex)
Title: World Energy Modelling $EM DASH$ 2: Preliminary Results from the Petroleum/Natural Gas Model
Author: R. J. Deam, J. G. Hale, J. R. Isaac, J. Leather, F. M. O'Carroll, P. V. Slee, P. C. Ward, P. L. Watson
Affiliation: University of London
Sponsor: --
Source: Proceedings of the Energy Model Workshop, London, England, October 15-19, 1973, pp. 91-117. Available from IPC Business Press, Guildford, Surrey, England, 1974.
Date: October 1973
Abstract: A series of global oil and gas environments representing the year 1977 have been examined using the Queen Mary College World Oil and Gas Model. The analyses cover world oil and gas production, supply, refining and product demand, and highlight the global effects of policy changes within the United States. Policy options examined include: (1) meeting some U.S. natural gas demand with oil products; (2) prohibiting new refinery construction on the U.S. East Coast; (3) enforcing lower sulfur limits on U.S. fuel oil; (4) assuming Alaskan North Slope crude oil becomes available. The effects on world investments in refinery plant and tankship building, crude and product prices, energy consumption and national revenues for the various scenarios are examined.

Entry Number: 659661 (Compendex)
Title: Energy Models and Forecasts: a User's Point of View
Author: Patrick P. McCall
Affiliation: Exxon Corp.
Sponsor: National Science Foundation
Source: NTIS; Report No. LBL-3635
Date: June 1974
Abstract: Currently, Exxon uses a linear program for the world oil industry. It is highly disaggregated by geographical region, refining technology, transportation technology, and type of oil. It is used to forecast future oil prices and to provide a framework for facilities planning. It is not a

short run model; another linear program for the short run incorporates facilities constraints. The Wharton model (plus a great deal of judgment) is used to trace the impacts of oil shortages.

Entry Number: 688939 (NTIS)
Title: Sensitivity Analysis of a Linear Programming Model of Petroleum Economics: The Influence of Large Price and Demand Uncertainties upon Consumption, Expenditures, and Shortages
Author: Howard B. Levine
Affiliation: Systems, Science and Software
Sponsor: National Science Foundation
Source: Systems, Science and Software (La Jolla, CA) or NTIS; Report No. PB-288 837/8
Date: December, 1974
Abstract: A computer program incorporating the technique of global sensitivity analysis was exercised on a linear programming model of petroleum refining economics. For testing purposes, simplified parametric price-demand relations were employed. The study shows that the global sensitivity approach provides direct and accurate determiniation of the significant parameters of the system.

Entry Number: 876547 (Compendex)
Title: Economic Incentives in the Exploration, Extraction and Refining of Crude Oil
Author: A. Pagoulatos, David Debertin, E. Pagoulatos
Affiliation: University of Kentucky, Lexington
Sponsor: UMR-DNR (U. of Mo. - Rolla/Mo. Dept. of Natural Resources) Conference on Energy
Source: University of Missouri - Rolla, Extension Division, Fourth Conference on Energy (1978), pp. 427-436.
Date: October 1977
Abstract: A simultaneous econometric model consisting of 37 stochastic equations and 3 identities which captures the decisions affecting the supply of new discoveries, the size of proven reserves, the production out of reserves, the demands and supplies of refined products and the imports of crude oil and refined products, is estimated. Simulation with the econometric model analyzed the effect of alternative pricing policies on domestic oil production, consumption and imports.

Entry Number: 918488 (DOE Energy Database)
Title: Oil Refinery Modeling with the GAMS Language
Author: D. Kendrick, A. Meeraus, J. S. Suh
Affiliation: University of Texas, Austin
Sponsor: --
Source: University of Texas at Austin; Center for Energy Studies, Research Report No. 14
Date: November 1981
Abstract: Linear programming models of oil refineries have been used for many years. However, the process of constructing, modifying and debugging these models is time consuming and tedious. The General Algebraic Modeling System (GAMS) language offers potentially large increases in productivity for model builders. In particular, it offers substantial productivity

increases for investigators who construct and use oil refining models. Therefore, this paper provides an application of the GAMS language to a familiar textbook oil refining model. The resulting computer input is relatively easy to understand and to modify.

Entry Number: 921661 (NTIS)
Title: Fuel Quality Processing Study. Volume I.
Author: J. B. Ohara, A. Bela, N. E. Jentz, H. T. Syverson, H. W. Klumpe
Affiliation: Ralph M. Parsons Co. (Pasadena, CA)
Sponsor: National Aeronautics and Space Administration
Source: NTIS; Report No. DOE/NASA/0183-1
Date: April 1981
Abstract: This study evaluated the feasible paths from liquid fossil fuel sources to generated electricity. The segments from which these paths were built are the results from the fuel upgrading schemes, on-site treatments, and exhaust gas treatments described in Volumes II-IV. This volume, Overview and Results, summarizes the results of the study.

Entry Number: 926535 (DOE Energy Database)
Title: Analysis of the World Oil Market
Author: H. D. Jacoby
Affiliation: MIT
Sponsor: --
Source: NTIS; Report No. PB-81-141319
Date: April 1978
Abstract: The world oil market was analyzed using two types of models, one representing capital behavior and the other a detailed simulation model of market supply and demand. The investigation involved a set of studies of oil supply from key producer areas, impact demand from major consumers, and integration of estimated supply and demand functions into a simulation model for studying future developments. The simulation framework was combined with a separate set of behavioral models of the cartel-core nations and their price-setting decisions, together with studies of evolving contract arrangements, trade patterns, and financial factors. This research increases understanding of the workings of the world oil market and the likely effects of various national policies.

Entry Number: 1010387 (DOE Energy Database)
Title: Investment-Planning Model for the Oil-Refining and Petrochemical Industries in Korea
Author: J. S. Suh
Affiliation: University of Texas, Austin
Sponsor: PhD Thesis
Source: University Microfilms; Order No. 82-08,260.
Date: 1981
Abstract: The investment planning model presented in this paper combines information from both the oil-refining industry and the petrochemical industry in order to consider how the Korean economy can best use limited availability of crude oil. A static and dynamic model are constructed. In building the linear programming model, a special computer language called GAMS (General Algebraic Modeling System) is used.

Entry Number: 1022233 (DOE Energy Database)
Title: Engine Trends: Impact on Refining
Author: J. C. Dickson et al
Affiliation: Bonner and Moore Associates, Inc.
Sponsor: --
Source: Hydrocarbon Processing, Volume 61, Number 5 (May, 1982), pp. 155-159.
Date: May 1982
Abstract: This study examines the impacts on petroleum refining that might be associated with various engine development programs. Each development scenario is defined in terms of the mix of new vehicles which might be introduced into the total vehicle population. By imposing one, or a combination of these demand profiles on models of regional refining capabilities, impacts of various engine development programs were derived from the behavior of the refining models.

Entry Number: 1099796 (DOE Energy Database)
Title: Resources and Energy: An Economic Analysis
Author: F. E. Banks
Affiliation: --
Sponsor: --
Source: Lexington Books, Lexington, MA
Date: 1983
Abstract: Two long core chapters on oil and nonfuel minerals, along with an exposition of the econometrics of primary commodities, give the reader a basic insight into the economic techniques and their uses. There are also chapters on coal, gas, and uranium, which include an overview of the Soviet energy sector and the Australian coal industry. The book introduces oil refining, petrochemicals, futures markets, inventories, capital costs, tin, iron and steel, stock-flow models, and other topics not usually handled in economics texts.

Entry Number: 1116301 (DOE Energy Database)
Title: Investment Model for the U.S. Gulf Coast Refining/Petrochemical Complex
Author: V. C. Langston
Affiliation: Texas Energy and Natural Resources Advisory Council, Austin
Sponsor: same
Source: NTIS, Report No. TENRAC/EP-83-003
Date: March 1983
Abstract: The U.S. Gulf Coast refining complex must choose competitively the location of future processing investment. A multi-period, multi-region, multi-product, multi-process linear programming model is developed to analyze investment decisions under selected scenarios. The supply-side modeling incorporates detailed technical information about production processes and products to predict efficient process utilization among refining centers over time.

Entry Number: 1134007 (Compendex)
Title: Survey of Nonlinear Programming Applications
Author: Leon S. Lasdon, Allan D. Waren
Affiliation: University of Texas (Austin)
Sponsor: --
Source: Operations Research, Volume 28, Number 5 (September/October 1980), pp. 1029-1073.
Date: September 1980
Abstract: Illustrations of the potential of NLP (nonlinear programming) models are presented by describing the application of NLP models to three classes of problems: petrochemical industry applications, nonlinear networks, and economic planning. Problems in the petrochemical industry range from product blending, refinery unit optimization, unit design to multiplant production,and distribution planning. The nonlinear networks topics include electric power dispatch, hydroelectric reservoir management, and problems involving traffic flow in urban transportation networks. In economic planning, the authors describe NLP applications involving large dynamic econometric models, a variety of static equilibrium models, and submodels of larger planning systems. In each area the problem is considered and its nonlinear model, algorithms, software systems, and (where available) benefits are described.

Entry Number: 1141791 (NTIS)
Title: Fuel Quality Processing Study. Volume III.
Author: George E. Jones, Jr., P. Bruggink, C. Sinnett
Affiliation: Gulf Research & Development Co. (Pittsburgh, PA)
Sponsor: National Aeronautics and Space Administration
Source: NTIS; Report No. DOE/NASA/0183-3
Date: October 1981
Abstract: This study evaluated the feasible paths from liquid fgssyl fuel sources to generated electricity. The segments from which these paths were built are the results from the fuel upgrading schemes, on-site treatments, and exhaust gas treatments described in Volumes II-IV. This volume, Fuel Upgrading Studies, describes the methods used to calculate the refinery selling prices for the turbine fuels of low quality.

Entry Number: 1201692 (DOE Energy Database)
Title: Aggregate Oil-Refining Models: The Case of Energy-Economy Interactions in France
Author: D. Babusiaux, D. Champlon, M. Valais
Affiliation: Institut Francais du Petrole
Sponsor: --
Source: Energy Exploration and Exploitation, Volume 2, Number 2 (1983), pp. 143-153.
Date: 1983
Abstract: Models may be constructed and used to represent, on an aggregate level, the entire refining industry of a country (France) or of a given geographic zone. The first part of the article analyzes the aggregation problems that arise during linear-programing modeling. These problems are particularly acute when the refining model has to be coupled with other models, because excessive simplifications may lead to irrelevant results. The second part of the article gives some application examples. The final part describes the formulation retained for representing the petroleum

sector in the Mini-DMS (Dynamique Multi-Sectoriel) Energie model. The refining industry is characterized by equations of the econometric type estimated on the basis of artificial sampling.

Entry Number: 1216950 (DOE Energy Database)
Title: Impacts of alcohol fuels on the U.S. Refining Industry (2 volumes)
Author: J. C. Dickson, F. P. Frederick, W. W. Sipowicz
Affiliation: Bonner and Moore Management Science, Houston,TX
Sponsor: --
Source: NTIS; Document No. DOE/CS/50007-1-Vol. 1
Date: August 1983
Abstract: The study assesses the impact alcohols, as a vehicle fuel or as fuel components, would have on the U. S. petroleum refining industry. Assessing these impacts was accomplished by studying the behavior of two sets of mathematical models of refining operations. One set was composed of regional composite-refinery models which were used to find the optimum balance of operating and capital costs under specified future conditions. The other set of models, referred to as simulation models, was used to examine a series of specific refinery situations encompassing those which individual refiners may encounter.

Entry Number: 1227544 (DOE Energy Database)
Title: Rising Diesel Demand -- A Linear Programming Challenge
Author: G. W. Michalski, G. H. Unzelman
Affiliation: Ethyl Corporation
Sponsor: National Petroleum Refiners Association, Washington, DC
Source: National Petroleum Refiners Association, Technical Paper No. AM-83-49
Date: March 1983
Abstract: Past, present and future applications for linear-programming computer models are discussed in this paper. The fact that gasoline represented about half of refinery output and contributed more than half of refinery profit provided the driving force for using this new technology. A fairly current application of these refinery models is in crude oil selection and crude evaluation.

Entry Number: 1386244 (Compendex)
Title: Modelling the U. S. Refining Industry for Facilities Planning
Author: J. H. Bryant, Neal J. Cleary, Milton M. Gutterman
Affiliation: Standard Oil Company (Indiana)
Sponsor: National Petroleum Refiners Association (NPRA)
Source: Proceedings of the NPRA Computer Conference, Houston, Texas, Nov. 1-4, 1981. (Published by NPRA, Washington, DC, 1981).
Date: November 1981
Abstract: The Department of Energy requested the National Petroleum Council to assess the ability of the domestic refining industry to meet demands for essential petroleum products. The Refining Capability Task Group, formulated by the NPC, utilized a refinery modeling system developed by Bonner & Moore Associates, Inc. to estimate future facility requirements and the ability of the industry to respond to various scenarios of supply and demand. This paper emphasizes the LP model construction and validation effort.

II. Other Literature

Title: Costs and Benefits of Reducing Lead in Gasoline.
Author: Joel Schwartz, Jane Leggett, Bart Ostro, Hugh Pitcher and Ronnie Levin
Affiliation: U.S. Environmental Protection Agency. Office of Policy Analysis. Economic Analysis Division.
Sponsor: --
Source: Environmental Protection Agency, Report Number EPA-230-03-84-005
Date: March 1984
Abstract: The report estimates the costs and benefits of reducing lead in gasoline. Eliminating or severely limiting lead content is estimated to increase manufacturing costs by less than 1%. In contrast, the benefits from automobile maintenance savings, reductions in misfueling and improved health are estimated to be substantial.

Title: An Econometric-Linear Programming Model of the U.S. Petroleum Refining Industry
Author: F. Gerard Adams, James M. Griffin
Affiliation: University of Pennsylvania (Philadelphia, PA)
Sponsor: --
Source: Quantitative Models of Commodity Markets, edited by Walter C. Labys (Cambridge, MA: Ballinger Publishing Company, 1975).
Date: 1975
Abstract: This article describes an econometric-linear programming model of the petroleum industry. The model is intended to provide a medium term perspective over the business cycle and to serve as a framework for long-term projections. It can also be used as a tool for simulation studies under alternative assumptions about economic conditions or policies. Given product demands, inventory adjustments, and net imports, the requirements for the major petroleum products are determined and become endogenous constraints on the linear-programming (LP) model. The objective function is then set to minimize output production costs, and the LP solution determines the volume of crude oil inputs required, capacity utilization measures, total operating costs, and the outputs of by-products.

Title: An Econometric Study of the United States Petroleum Industry
Author: Jack W. Wilkinson
Affiliation: Temple University
Sponsor: PhD Thesis
Source: University Microfilms; Order No. 74-28, 380
Date: 1974
Abstract: This study builds a short-run macroeconometric description of petroleum industry supply, demand, and price behavior. It then forecasts demand for crude petroleum and petroleum products, the supply response of refiners and producers, and crude petroleum product prices.

Title: Economic Impact of Sulfur Dioxide Pollution Controls
Author: R. N. Gamse and J. Speyer
Affiliation: Environmental Protection Agency. Office of Planning and Evaluation. Economic Analysis Division.
Sponsor: --
Source: Chemical Engineering Progress, Volume 70, Number 6 (June 1974) pp. 45-8.
Date: June 1974
Abstract: Brief discussion of the economic impact of sulfur dioxide emissions regulations. Includes the following issues: background of the Clean Air Act Amendments of of 1970, the EPA Clean Fuels Policy and State Implementation Plans, stack gas cleaning costs and impacts, fuel switching (from high to low sulfur fuels), atmospheric dispersion through tall stacks and supplemental control systems, and nondegradation of air quality versus economic growth.

Title: Economics of Refinery Sulfur Management
Author: R. E. Conser
Affiliation: UOP Inc. (Des Plaines, IL)
Sponsor: --
Source: Air Pollution Control and Clean Energy, edited by Charanjit Rai and Lloyd A. Spielman. American Institute of Chemical Engineers Symposium Series, Volume 72, Number 156, pp. 23-32.
Date: 1976
Abstract: Economics of sulfur dioxide emission control techniques for combustion sources and fluid catalytic cracking units are compared, considering crude type, product objectives and other factors. New technology and synergistic combinations are discussed.

Title: Effects of Federal Policies on Gasoline Consumption
Author: James L. Sweeney
Affiliation: Energy Modeling Forum, Stanford University
Sponsor: Department of Energy (Office of Conservation Policy and Planning) and the Electric Power Research Institute
Source: Resources and Energy, Volume 2 (1979), pp. 3-26.
Date: 1979
Abstract: Utilizing theory and econometric evidence, the paper provides rough quantitative estimates of the impacts on passenger car gasoline consumption of several Federal policies. Three distinct time periods are distinguished: pre-embargo, post-embargo but before new car efficiency standards, and post-standards. In the pre-embargo period policies tend to tend to reduce gasoline consumption, while for the four years after the embargo such policies tend to encourage consumption. The new average car fuel efficiency standards greatly influence passenger car efficiency by forcing increases in fleet efficiency; with these standards in operation, other policies have little or no incremental effect on efficiency. For the post-standards era, the net impact of Federal programs will be a reduction in gasoline consumption and a decrease in price elasticity of passenger car gasoline demand.

Title: Energy Model Comparison: An Overview
Author: James L. Sweeney
Affiliation: Energy Modeling Forum, Stanford University
Sponsor: --
Source: Large-Scale Energy Models: Prospects and Potentials. Robert M. Thrall, editor. (Boulder, Colorado: Westview Press, 1983), pp. 191-217.
Date: 1983
Abstract: Paper discusses the benefits systematic model comparisons can provide through identification of errors, clarification of disagreements, and guidance in model selection. Model comparison categories include methods and equations, forecast, aggregate behavior, and model regeneration.

Title: Energy Modeling and Aggregation of Refining
Author: D. Babusiaux, M. Valais
Affiliation: Institut Francais du Petrole, France
Sponsor: --
Source: Modelling of Large-Scale Energy Systems: Proceedings of the IIASA/IFAC Symposium, February 25-29, 1980. Volume 12 edited by W. Hafele (NY: Pergamon Press, 1980).
Date: 1980
Abstract: The Institut Francais du Petrole has compiled several dynamic linear programming models that need an aggregate representation of the refining industry. To simplify, it might be possible to assimilate the whole set of French refineries into a single refinery. However, the value of the dual variables may be rather different from the values of marginal costs that can be observed. This is due to structural and regional differences among refining centers. The accuracy of an aggregation method is evaluated by studying the marginal costs of products. This is of particular importance in cases where the model (refining) is to be connected with the model of another sector (electricity production) employing as an input the output of the first sector (heavy fuel oil).

Title: Impact Assessment of Reducing Gasoline Volatility
Author: Bonner & Moore Management Science (Houston, TX)
Affiliation: same
Sponsor: California Air Resources Board
Source: Research Division, California Air Resources Board; Contract No. A2-051-32
Date: November 30, 1983
Abstract: This study assessed the impacts of lowering the allowable vapor pressure of gasoline during the summer period. Impacts included in the assessment are effects on hydrocarbon emissions, on vehicle performance, on crude requirements, on process investments and on refining costs. Two future situations were examined, projecting environments for 1985 and 1990.

Title: Petrochemicals in Texas - 1972.
Author: The Pace Company Consultants & Engineers, Inc.
Affiliation: same
Sponsor: The State of Texas, Governor's Energy Advisory Council, Subcommittee of the Petrochemical Energy Group.
Source: The State of Texas, Governor's Energy Advisory Council, Subcommittee of the Petrochemical Energy Group, Special Project C, January 30, 1974.
Date: January 30, 1974.
Abstract: The report defines the present and future status of the petrochemical industry in Texas relative to the rest of the United States. Part I presents the current status of petrochemical company location, capacity, feedstock requirements and feedstock source. Part II estimates the growth in these parameters over the next ten years, based upon the location of new refinery capacity and other factors.

Title: The Process Analysis Alternative to Statistical Cost Functions: An Application to Petroleum Refining
Author: James M. Griffin
Affiliation: Standard Oil Company (New Jersey)
Sponsor: Drawn from PhD thesis at University of Pennsylvania
Source: The American Economic Review, Volume 62 (March 1972), pp. 46-56.
Date: March 1972
Abstract: The paper investigates whether the process analysis approach to cost curves offers new insights into cost curve analysis and yields results which are more in accord with theory. Most statistical cost function studies show marginal cost to be constant. This paper uses process analysis rather than a statistical cost analysis approach to yield the classical short-run cost function properties -- rising marginal costs and a U-shaped average cost function. Relevant details about the production function, the aggregation conditions, and the treatment of technological change are introduced in Section I. A process analysis approach is used in Section II to derive the cost curve in the single product case. Section III extends the analysis to the joint product cost curve, and emphasizes the dependency of product outputs on relative product prices.

Title: Refinery Energy Modeling System (REMS) Database Documentation
Author: DOE. Energy Information Administration. Office of Oil and Gas.
Affiliation: same
Sponsor: --
Source: Report Number DOE/EIA-0461
Date: October 1984
Abstract: The document provides a description of the 1983 database associated with Version I of the Refinery Evaluation Modeling System (REMS) of the Energy Information Administration (EIA). The database consists of model data tables which are input directly into REMS in machine-readable form and source data tables which present associated data extracted from primary source documents. The two sets of tables provide a description of all model input data, including the definitions of data elements, data sources and units of measurement.

Title: Refinery Energy Modeling System (REMS) Model Documentation
Author: DOE. Energy Information Administration. Office of Oil and Gas.
Affiliation: same
Sponsor: --
Source: Report Number DOE/EIA-0460
Date: October 1984
Abstract: The document provides a description of Version I of the Refinery Evaluation Modeling System (REMS) of the Energy Information Administration (EIA). This description includes the mathematical representation of both components of REMS: the Regional Yield Models (RYMs) and the Oil Refinery and Distribution Model (ORAD). It also provides an explicit statement of the linear programming formulation of both the RYMs and ORAD, including the row and column structure. To assist those expecting to execute REMS, the document also contains a computer software program operations manual, a program maintenance manual and a user's guide.

Title: Refinery Operations Monitoring and Control -- History and Trends
Author: Joe F. Moore, Pat B. Truesdale, W. W. Sipowicz
Affiliation: Bonner & Moore Associates, Inc.
Sponsor: National Petroleum Refiners Association (NPRA)
Source: Proceedings of the NPRA Computer Conference, Tulsa, OK, October 30 - November 2, 1983. (Published by NPRA, Washington, DC, 1983).
Date: November 1983
Abstract: The paper summarizes the history of Refinery Operations Monitoring and Control (ROMC) models, and provides some insights into future uses of the models in the following areas: yiels accounting, on-line data acquisition, blend monitoring or control, oil movements monitoring or control, and scheduling.

Title: Regulatory Impact Analysis of Proposed Rules Limiting the Lead Content of Gasoline (Draft).
Author: U.S. Environmental Protection Agency. Office of Policy Analysis. Economic Analysis Division
Affiliation: same
Sponsor: --
Source: Washington, DC: Environmental Protection Agency, July 23, 1984.
Date: July 23, 1984
Abstract: EPA is proposing a rule to reduce the lead content of leaded gasoline from current limits of 1.1 grams per leaded gallon (gplg) to .1 gplg in 1986. Since the proposed rule is "major" (increases in gasoline production costs are expected to exceed $100 million per year), a Regulatory Impact Analysis (RIA) is required and is undertaken in this document. An overview of the lead problem is provided in Chapter I, and alternative regulatory approaches are presented in Chapter II. Costs are estimate in Chapter III, and various benefits in Chapters IV-VI.

Title: <u>Residuals Management in Industry: A Case Study of Petroleum Refining.</u>
Author: Clifford S. Russell
Affiliation: Resources for the Future, Inc.
Sponsor: --
Source: Washington, DC: The Johns Hopkins University Press, 1973.
Date: 1973
Abstract: To analyze the costs of residuals management policies, the author has developed an industrial model which is applied to a hypothetical petroleum refinery. The model is designed to allow improvements in cost estimation, simultaneous consideration of air, water and solid waste problems, and reflection of changing patterns of input costs and output quantity and quality.

Title: RPMS: The Refinery and Petrochemical Modeling System - A System Description
Author: Bonner & Moore Management Science (Houston, TX)
Affiliation: same
Sponsor: --
Source: see Author
Date: --
Abstract: RPMS is a computer-based management tool. Consisting of both processors and extensive data libraries, the system permits the rapid construction and solution of linear programming models to address complex economic analysis and planning problems within the refining and petrochemical industries. RPMS has been used to assess the economic impact which accompanies various technological, economic and regulatory changes affecting the refining and petrochemical processing industries, segments of these industries, and related industries. This document describes both the basic RPMS package and the supplementary packages (processors and data bases) which have been added to the RPMS during systems development.

Title: A Study of the Demand for Gasoline
Author: Philip K. Verleger, Jr. and Dennis P. Sheehan
Affiliation: Yale University and the University of Rochester
Sponsor: The U.S. Environmental Protection Agency and the Council on Environmental Quality
Source: Chapter 4 of <u>Econometric Studies of U.S. Energy Policy</u>, edited by D. W. Jorgenson (Amsterdam: North-Holland Publishing Company, 1976).
Date: 1976
Abstract: The authors study the impactof the price of gasoline and per capita disposable income on per capita gasoline consumption by state in the United States. They estimate lags in the response of gasoline demand to changes in gasoline prices by means of a dynamic model of U.S. demand for gasoline. The authors demonstrate that the cost of gasoline is the most important determinant of the variable cost of operating an automobile.

Title: Survey of Texas Petroleum Refineries.
Author: Texas Mid-Continent Oil and Gas Association
Affiliation: same
Sponsor: The State of Texas, Governor's Energy Advisory Council (TENRAC)
Source: The State of Texas, Governor's Energy Advisory Council, Special Project B, October 15, 1974.
Date: October 15, 1974.
Abstract: This report provided summary information on existing refinery processing capacity, sources of feedstock, and time-capacity projections of refinery capacity for the state of Texas. The information was obtained using survey data from Texas refiners.

Title: A Texas Perspective on Energy Issues.
Author: Vicky Langston (editor)
Affiliation: Energy Policy Division, The Texas Energy and Natural Resources Advisory Council (TENRAC)
Sponsor: same
Source: same
Date: August 1983.
Abstract: This document is one of a series of annual outlook for energy markets reports. Papers by the Energy Division Policy staff and contract consultants are presented, grouped into six issue areas: oil and gas production issues, natural gas market issues, refining issues, electric utility issues, energy tax issues, and 1984 energy issues and re-election.

Title: U. S. Energy Model Documentation
Author: Data Resources, Inc.
Affiliation: same
Sponsor: same
Source: same
Date: Spring 1984
Abstract: The document is a detailed discussion of the 1984 version of the DRI U. S. Energy Model. Chapter I and the introductory sections of each of the following chapters (Energy Prices, Energy Supplies, Residential Energy Demands, Commercial Energy Demands, Transportation Energy Demands, Electric Utility Generation and Fuel Requirements) provide a concise overview of the model's methodology. The remaining sections go through the model equation by equation, defining the variables and presenting the rationale behind the equation formulations.

APPENDIX B

SUMMARY OF INSTITUTIONS AND CAPABILITIES

This Appendix lists information on agencies and organizations involved in economic/petroleum refinery modeling. The organizations are listed in alphabetical order; addresses and (where possible) names and telephone numbers of knowledgeable individuals are also given. In many cases, more than one person was contacted: only the most applicable name is given. At several institutions, petroleum refinery modeling research is no longer in progress. At these agencies, the name and address of the organization is noted, but no contact is given.

American Petroleum Institute

1220 L Street, NW
Washington, DC 20005
(202)457-7000

API was established in 1919 as the first national trade association in the United States to encompass all branches of the petroleum industry. API conducts research on various aspects of the petroleum industry. However, much of the economic modeling has emphasized measures of integration and concentration; petroleum refining modeling has been left to private firms to undertake. Environmental analyses focus upon the cost of control technology to various segments of the industry and evaluations of the cost impact of various regulations on the industry.

Arthur D. Little, Inc.

Acorn Park
Cambridge, MA 02140
Mr. John Felten
(617)864-5770

ADL is involved in a variety of industrial research, engineering, and management consulting activities, and utilizes over 2300 employees in various forms of research and consulting. The Energy Economics portion of ADL is headed by Nigel Godley, who was a major contributor to a series of reports on the petroleum refining industry that were done for the Environmental Protection Agency in the 1970's. These studies analyzed the impacts of anticipated EPA lead and SOx regulations on petroleum refining. Although the initial versions of the study treated the refinery industry as if it were one "average" refinery, the final studies used clusters of representative refineries and seven regions. (Note: one of the key analysts in the early work left ADL and began similar work at Sobotka).

Bonner & Moore Management Science, Inc.

2727 Allen Parkway
Houston, TX 77019
Mr. Frank Frederick
(713)522-6800

Although relatively small (150 employees), Bonner and Moore is one of the most widely used operational and management consulting services in the energy industry. B&M has made extensive use of linear programming models of the petroleum refining industry; for the last 15-20 years, these proprietary models have been used by many refiners, and have also formed the basis of studies of the petroleum refining industry which have been undertaken by DOE, EPA, and many other public agencies. Recently, B&M did a study for the California Air Resources Board assessing the cost of reducing gas volatility to reduce hydrocarbon emissions: it was based on a proprietary model that was specific to California.

California Energy Commission

Assessments Division
1516 9th Street
Sacramento, CA 95814
Mr. Ramesh Ganeriwal
(916)324-3103

The Assessments Division of the California Energy Commission (CEC), in conjunction with Robert Brown Associates (Carson, CA) developed a process model of the California petroleum refining industry. The model uses the inputs and outputs of crude slated for the next twenty years, asks what the projected slate will be, and estimates purchased and self-generated energy requirements for the petroleum refining industry. The model has an input-output side, and some energy information, but is missing the costing portions.

Data Resources, Inc.

24 Hartwell Avenue
Lexington, MA 02173
(617)863-5100

DRI is an information services company, specializing in econometric models and forecasting. However, the models are "demand oriented" -- the detail included is a function of the number of requests for such information. Thus, the refinery portion of the energy sub-models is not emphasized. Costs of operating a refinery are in aggregated categories (e. g., O&M, capital, inventories, crude) and on a national basis; the cost escalators are national cost escalators, pulled from the DRI Price Forecast Models. A rate of return is assumed (rather than endogenous) and used to estimate the cost a refinery must obtain per barrel and the volume (weighted per barrel) of products sold to cover revenues. Thus, the DRI model must assume some sort of air quality impact on costs, rather than modeling this information endogenously.

Department of Energy

1000 Independence Avenue SW
Washington, DC 20585

Economic Regulatory Administration.
(202)252-5806

ERA was responsible for the enforcement of federal statutes and regulations in effect prior to the decontrol of crude oil and petroleum product prices in January 1981. Within ERA, the Office of Special Counsel (OSC) is in charge of enforcement and compliance activities. To assist OSC in work related to auditing oil refineries, ERA sponsored some work at Oak Ridge National Laboratory (ORNL) on the development of methods, and computer implementation of those methods, to analyze data from oil refineries. The work was to be based upon models developed at Bonner & Moore and Turner-Mason. However, due to difficulties with the proprietary nature of those models, the work has been discontinued at OSC request, and no models or reports are forthcoming. The manager of the DOE/OSC work has left DOE; questions regarding the current OSC/ORNL interactions are to be referred to

Mr. Wayne Range, the DOE Information Officer at Oak Ridge. Mr. Range can be reached at (615)576-0885.

Energy Information Administration.
Mr. John Conti
(202)252-5996

EIA is chiefly known for its data collection and reporting functions. However, EIA also interprets and publishes data on domestic and international production, utilization and distribution of crude oil and refined petroleum products, and analyzes and projects availability of petroleum supplies. One of the current models under development at DOE/EIA is the Refinery Energy Modeling System (REMS), which is an update of the Turner-Mason model. REMS is a domestic model, set up to depict an average refinery in each of five regions.

Department of Transportation

Office of Assistant Secretary for Policy, Plans and International Affairs
TPI-34
400 Seventh Street, SW
Washington, DC 20590

The Transportation Department's Office of Assistant Secretary for Policy, Plans and International Affairs (OASPPI) sponsored a study on the economic aspects of refinery and deep-water port location in the United States in 1974. However, the study emphasized the construction of pipelines so that barrel-miles of petroleum transportation were optimized, rather than refinery costs and/or outputs. Thus, the study was not relevant to the current petroleum refining study, and recent Transportation Department research has not been applicable.

Electric Power Research Institute

3412 Hillview Avenue
Post Office Box 10412
Palo Alto, CA 94303
(415)855-2000

The Electric Power Research Institute (EPRI) receives its funding from a consortium of member organizations (mostly electric utilities) and uses these funds to sponsor research in areas applicable to electric power generation. Some of the environmental and modeling efforts supported by EPRI are applicable to the present study, and are cited in Appendix A.

Energy Modeling Forum

406 Terman Engineering Center
Stanford University
Stanford, CA 94305
(415)497-0645

As suggested by the organization name, the Energy Modeling Forum (EMF) is mainly concerned with development and evaluation of energy models. Activities of EMF are funded by gifts from corporate affiliates (composed primarily of oil and other energy companies) and by grants or contracts with the U.S. Department of Energy and the Electric Power Research Institute. However, the EMF models operate at the world level and emphasize crude oil extraction and movement. These models are therefore not readily applicable to California or to the petroleum refining industry.

<u>Environmental Protection Agency</u>

Office of Mobile Sources
401 M Street SW
Washington, DC 20460
Mr. Barry Nussbaum
(202)382-2637

EPA administers federal environmental policies, research, and regulations; and provides information on a variety of environmental subjects, such as water pollution, hazardous and solid waste disposal, air and noise pollution, pesticides, and radiation. The most recent work relevant to this study is the proposed changes in gasoline lead regulations. However, the modeling is not done at EPA. A DOE model is used by a contractor (Sobotka Associates).

<u>Environmental Quality Laboratory</u>

California Institute of Technology 314-40
Pasadena, CA 91125
(213)356-4167

The Environmental Quality Laboratory (EQL) is the focus of environmental research on the CalTech campus. Much effort has been spent on air quality modeling, in an attempt to understand how emissions are translated into air quality. One study which related to the petroleum refining industry analyzed the feasibility of pollution permits. To forecast the demand for such pollution permits, the marginal costs of pollution control for various industries (including petroleum refining, glass and other industries) were estimated.

<u>International Institute for Applied Systems Analysis</u>

2361 Laxenburg
Austria

IIASA is a research institute whose members are not individual nations, but instead are scientific institutions from 17 participating nations. (For example, the National Academy of Sciences, The Royal Society of London, the Academy of Sciences of the Union of Soviet Socialist Republics, and the Swedish Committee for Systems Analysis are all members). IIASA applies analytic tools to major problems of global concern. For example, IIASA has research programs on energy systems, and food and agriculture; areas of research include resources and the environment, human services and settlements, mamagement and technology, and systems and decision sciences. One of the research papers written at IIASA was an overview and critique of several energy models.

Lawrence Berkeley Laboratory

University of California - Building 50B
Berkeley, CA 94720
(415)486-4000

The Lawrence Berkeley Laboratory (LBL) was involved in energy modeling research in the early 1970's. One of the LBL studies is referenced in Appendix A (Entry Number 659661). However, no applicable research has been done in the last ten years, and much of the energy work has migrated to the Energy Resources Group at UC Berkeley, headed by John Holdren.

Maryland Department of Community and Economic Development

Division of Research
2525 Riva Road
Annapolis, MD 21401

The Maryland Department of Community and Economic Development (DECD) was included in the survey of potential research leads because Hyder Lakhani, an economist with DECD, had written several documents on the diffusion of environment-saving technological change in which petroleum refining had been the focus of analysis. However, since the research emphasized technology diffusion modeling rather than petroleum refinery modeling the work was not pursued.

MathTech (A Division of Mathematica, Inc.)

14 Washington Road
Princeton Junction, NJ 08550
Mr. Ernie Manuel
(609)799-2600

Mathematica is a subsidiary of Martin Marietta Corporation, and is involved in a variety of research areas -- software products, policy research, operations research, economic analysis, systems analysis. MathTech is the portion of Mathematica involved in air quality issues. MathTech studies are usually done in conjunction with Argonne National Laboratory. Argonne models emissions sources using the NEDS (National Emissions Data System) emissions, MathTech uses these emissions estimates and calculates the reduced impacts on health. Thus, MathTech focuses on the costs and benefits of air quality standards, but from a source inventory/air quality controls/benefits estimation route, rather than using process models and appending air quality data.

National Aeronautics and Space Administration

400 Maryland Avenue, SW
Washington, DC 20546

In the early 1970's, the National Aeronautics and Space Administration (NASA) funded a number of studies on fuel processing from alternative energy sources. As a portion of these studies, the impact on petroleum refinery costs and capacity were assessed, using models developed by Bonner & Moore. The work has not been pursued in recent years.

National Oceanic and Atmospheric Administration

Department of Commerce
1401 K Street, NW
Washington, DC 20230

The National Oceanic and Atmospheric Administration (NOAA) sponsors research on marine and lower atmospheric phenomena. One study, carried out at the University of Rhode Island's International Center for Marine Resource Development, evaluated the impact of offshore petroleum development on the New England economy. The emphasis was on building new refineries, and how these investments helped the New England economy. The NOAA-sponsored study was therefore not relevant to the current research effort on petroleum refining models, and no other NOAA work was applicable.

National Petroleum Refiners Association

Suite 1000, 1899 L Street, NW
Washington, DC 20036
(202)457-0480

As suggested by the organization name, the National Petroleum Refiners Association (NPRA) is a trade organization composed of firms engaged in petroleum refining activities. No modeling is done at NPRA; however, NPRA does sponsor annual conferences on computer modeling and on other petroleum refining issues. Some of these conference papers were of interest to the present study, and are referenced in Appendix A.

National Science Foundation

1800 G Street, NW
Washington, DC 20550

Early in the 1970's, the National Science Foundation (NSF) developed a Research Applied to National Needs (RANN) program, which attempted to fund research projects which were deemed to have high priority due to national interest and need. Several of these projects involved energy research, and one (carried out at Systems, Science and Software) examined how uncertainty affected linear programming models of the petroleum refining industry. The RANN program was dismantled in the late 1970's, and individuals who had sponsored energy-related research at NSF were moved out of the RANN office and into the Division of Policy Research and Analysis and the Division of Social and Economic Science at NSF.

Oak Ridge National Laboratory

Energy Division G-20
Bethel Valley Road
Oak Ridge, TN 37830
Dr. T. Randall Curlee
(615)576-4864

ORNL has been involved in energy and econometric work since the early 1970's. In January of 1973, ORNL began publishing the NSF-RANN Energy Abstracts. Most recently, ORNL was in charge of the refinery model evaluation for the Office of Special Counsel at DOE. However, that work was halted because of disclosure problems. Current work for the U. S. Navy looks at how changes in crude oil quality (toward heavier, higher sulfur crudes) around the world will change the specifications for end products such as jet fuels and diesel fuels.

Operational Economics, Inc. (OPCON)
802 West Alabama
Houston, Texas 77006
Dr. Russell G. Thompson
(713)528-3158

OPCON is a Houston-based management and economics consulting firm. It was founded in 1979 by Dr. Russell G. Thompson, who is the firm's chief executive officer. OPCON has completed special studies on crude oil, gasoline and fuel oil marketing; syngas potential on the Texas Gulf Coast; petrochemical economics; industrial demands for electricity and natural gas; prices of natural gas and competitive fuels in the 1980's; and future profit potential for the oil and gas industry. Through Dr. Thompson, the firm has been involved in a number of studies of residuals management in the petroleum refining industry.

The PACE Company Consultants and Engineers
Post Office Box 53473
Houston, TX 77052
Mr. Dan Foley
(713)965-0311

The PACE Company has developed a number of proprietary linear programming (LP) models of the petroleum refining industry. Most recently, PACE did a study of the entire US refining industry, using composite LP models to examine lead phase-down and foreign competition (import) issues. Three segments were included: the entire US, a "high complexity" segment representing 85% of the industry ("high complexity" referring to the pollution recovery capability available) and a "low complexity" segment, primarily composed of small refineries.

Pacific Northwest Regional Commission
700 E. Evergreen Blvd.
Vancouver, Washington 98661

As part of a series of studies commissioned by the Northwest Energy Policy Project (an effort funded by the Natural Resource Economics Division of the US Department of Agriculture), the Pacific Northwest Regional Commission co-sponsored an input-output study of the Washington-Oregon-Idaho area, to determine how major industries in the area (petroleum, paper and lumber) might be affected by various policy options and economic trends.

Resources for the Future

1755 Massachusetts Avenue, NW
Washington, DC 20036
Dr. Clifford S. Russell
(202)328-5055

RfF was founded in 1952 to study social science aspects of natural resource problems. Two recent studies are particularly applicable. One was completed in 1973 by Cliff Russell, and has been published as Residuals Management in Industry: A Case Study of Petroleum Refining. This was an integrated, residuals balance model of the petroleum refining industry, which includes quadratic as well as linear programming. "Outputs" include phenols, sulfur, nitrogen, solid wastes; both air and water emissions are included. The other study was led by V. Kerry Smith (now at Vanderbilt University) and Patricia Rice (affiliated with Oak Ridge National Laboratory). The Rice/Smith model looks at extraction as well as refining, but develops and estimates a model of the petroleum industry that includes both supply and demand.

Robert Brown Associates, Inc.

500 East Carson Plaza Drive -- Suite 215
Carson, CA 90745
Mr. Geoffrey Swett
(213) 770-3630

Robert Brown Associates (RBA) has a model for site-specific operations analysis (e.g., determining the profitability of buying or closing a refinery). The model uses weights and materials balances, and provides energy consumption and sulfur balance information, from which NOx and SOx emissions could be estimated. In 1982, some work RBA did for the California Energy Commission expanded the model to include energy conservation.

Sobotka & Company, Inc.

2501 M Street -- Suite 550
Washington, DC 20037
Mr. Terrence S. Higgins
(202)887-0290

Sobotka & Company, Inc. (SCI), founded in 1971, is a contract research firm specializing in economic and technical analysis of energy, transportation, and environmental issues. SCI has developed a refinery model which is a static linear programming simulator of refinery operations. The linear program matrix contains approximately 350 rows, 1100 variables and 8300 elements. The model has been used by EPA and DOE in a variety of applications; one of the most recent uses has been in the EPA lead phase-down work.

Southern California Edison Company

2244 Walnut Grove
Rosemead, CA 91770
(818)302-1212

Some attempt has been made at the Southern California Edison Company to model the demand for electricity by the petroleum refining industry, as part of an effort to model electricity demand by every 2-digit Standard Industrial Classification (SIC) industry grouping. However, no other modeling efforts related to the petroleum refining industry are in progress.

Systems, Science, and Software (S3)

Post Office Box 1620
La Jolla, CA 92037
(714)453-0060

S3 emphasizes simulation codes and software, and does high technology research for DOE, DOD, and other public agencies. The energy work (which is a relatively small proportion of S3 research) now emphasizes fluidized beds and coal gasifiers, geothermal and oil shale analysis. In the early 1970's, S3 obtained a grant from the Research Applied to National Needs (RANN) portion of the National Science Foundation to examine the effects of price and demand uncertainty on the results obtained from linear programming models of the petroleum refining industry. This work has not been pursued recently, and the Principal Investigator for the NSF study has left S3.

Texas Air Control Board

6330 Highway 290 East
Austin, TX 78723
Mr. Cyril Durrenberger
(512)451-5711

Modeling at the Texas Air Control Board, much like the effort at the CalTech Environmental Quality Laboratory, emphasizes emissions dispersion and meteorological conditions affecting ambient air quality. To date, no economic modeling of petroleum refineries has been done at the Texas Air Control Board.

Texas Public Utilities Commission

7800 Shoal Creek Blvd. -- Suite 400N
Austin, CA 78757
Ms. Carol King, Librarian
(512)458-0299

The Texas Public Utilities Commission was contacted in an attempt to track down a series of studies funded by the Texas Energy and Natural Resource Advisory Council (TENRAC: formerly the Texas Governor's Energy Advisory Council, and now disbanded). A multi-region, multi-period, multi-product, multi-process linear programming model was developed for the TENRAC studies to analyze petroleum refining decisions under a variety of scenarios. When

TENRAC disbanded, many of the individuals associated with the project went into other areas of research. Numerous telephone calls finally traced copies of the TENRAC reports to a librarian at the Texas Public Utilities Commission, who had formerly been the TENRAC document librarian.

<u>Turner, Mason and Associates</u>

400 North Olive
Lock Box 264
Dallas, TX 75201
Mr. Mel Turner
(214)754-0898

Turner-Mason developed some of the first linear programming models used by the petroleum refining industry. These models have also been used by the Department of Energy to evaluate alternative resource policies. However, these models are proprietary, and most of the reports are not in the public domain.

<u>University of Houston</u>

The Energy Institute at the University of Houston
Houston, TX 77004

The University of Houston received a large National Science Foundation grant (under the Research Applied to National Needs -- RANN -- program) to examine the costs which heavy industry would incur in meeting the guidelines of the 1972 Water Law (PL 92-500). This grant, and subsequent funding by the Texas Governor's Energy Advisory Council (later the Texas Energy and Natural Resource Advisory Council, now disbanded) and other organizations allowed the University to develop a large number of computer models of resource and policy issues. The results of several of these models are documented in reports referenced in Appendix A (See, for example, Entry Numbers 255434 and 403362). Relatively little funding has been available for this effort in recent years, and several of the Principal Investigators in the original NSF-sponsored work have left the university.

<u>University of London</u>

Energy Research Unit
Queen Mary College
University of London
London, England

The Energy Research Unit at the University of London has developed a World Oil and Gas Model known as $EM DASH$. The model estimates world oil and gas production, supply, refining and product demand situations under various scenarios. Publications based upon the model are referenced in Appendix A.

University of Missouri - Rolla

Extension Division
205 Parker Hall
Rolla, MO 65401

Since 1974, the University of Missouri, Rolla and the Missouri Department of Natural Resources (UMR-DNR) have co-sponsored annual conferences on energy. These conferences are meant to provide social scientists, natural scientists and engineers with a means for rapid communication of recent research on energy and to offer solutions to energy-related problems to local government. Some of the papers presented at these conferences are of use to the present project, and are summarized in Appendix A.

University of Rhode Island

International Center for Marine Resource Development
URI, Narragansett Bay Campus
Narragansett, RI 02882

The university of Rhode Island has a strong resource economics program and several centers and laboratories in which environmental and energy research are undertaken. One study, carried out by Thomas Grigalunas at the University of Rhode Island's International Center for Marine Resource Development, evaluated the impact of offshore petroleum development on the New England economy. The emphasis was on building new refineries, and how these investments helped the New England economy. The NOAA-sponsored study was therefore not relevant to the current research effort on petroleum refining models, and no other URI work was directly applicable.

University of Texas at Austin

Center for Energy Studies
Engineering Science Building 143
Austin, TX 78712

UT Austin houses a Center for Energy Studies, which is involved in energy conservation, electric power and environmental studies and in energy policy analyses. One recent project which was of use to this study was an oil refinery model which made use of the Generalized Algebraic Modeling System (GAMS) language. This study is referenced in Appendix A.

REFERENCES

This bibliography includes all documents discussed in the text as well as sources of further information on the economic, statistical, environmental and technical concepts discussed in the report. Citations followed by an asterisk (*) are discussed more fully in Appendix A. Those items which are followed by an asterisk and a number [e.g., (* 293568)] were identified during the formal literature search, and are found in numerical order in Part I of Appendix A. Those followed only by an asterisk were derived from personal contacts or were referenced in the cited literature: these listings appear with annotations in alphabetical order (by title) in Part II of Appendix A.

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