Environmental Conservation

The Oil and Gas Industries / Volume Two

Environmental Conservation

Prepared by the
National Petroleum Council
in response to a request from the
Department of the Interior

NATIONAL PETROLEUM COUNCIL

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and to the
OFFICE OF OIL AND GAS

Environmental Conservation

The Oil and Gas Industries
Volume Two

February 1972

A Report of the
National Petroleum Council's Committee
on Environmental Conservation—The
Oil and Gas Industries
W. W. Keeler, *Chairman*

with the assistance of the
Coordinating Subcommittee
Leo A. McReynolds, *Chairman*

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The Cover—*The photograph on the cover, which was made during the flight of Apollo 11, shows a spacecraft-window view of the Northern Hemisphere from the Pacific at left to the Mediterranean at right. Above the thin blue film of the earth's atmosphere at the curved horizon is the darkness of space.*

(Photo courtesy of the National Aeronautics and Space Administration)

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Foreword

The National Petroleum Council is an officially established industry advisory body to the Secretary of the Interior and, as such, represents virtually all segments of the U.S. oil and gas industries. At the request of the Assistant Secretary of the Interior—Mineral Resources, the Council undertook a comprehensive study of environmental conservation problems as they relate to or have an impact on the petroleum industry. It was asked to assure that its study placed all pertinent facts before the government officials who are charged with making policy decisions involving pollution control regulations which may affect oil and gas operations.

In order to respond to Interior's request, the National Petroleum Council established a special Committee on Environmental Conservation—The Oil and Gas Industries, under the chairmanship of W. W. Keeler, Chairman of the Board, Phillips Petroleum Company, and the cochairmanship of Hon. Gene P. Morrell, Deputy Assistant Secretary of the Interior—Mineral Resources. The Committee was assisted by its Coordinating Subcommittee, with Leo A. McReynolds, Director, Petroleum Products and Environmental Conservation, Phillips Petroleum Company, as its chairman. The Subcommittee was cochaired by Dr. Wilson M. Laird, former Director of the Office of Oil and Gas, succeeded by John Ricca, Deputy Director, U.S. Department of the Interior. A list of the Committee and Subcommittee memberships follows.

Because of the scope and complexity of the assignment, the study is presented in two volumes. Volume I contains the general comments and conclusions of the Council (reprinted in this volume) and a summary of the detailed data presented in this Volume II.

The NPC Committee on Environmental Conservation chose as a closing date for the study the conclusion of the 2nd session of the 91st Congress. Events of substantial import since that time are footnoted.

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Extracted from

Volume One
ENVIRONMENTAL CONSERVATION/
The Oil and Gas Industries

Prepared by the
National Petroleum Council

June 1971

Introduction

At certain points in time, society reaches an expressed or implied consensus as to the values it wishes to maximize or the goals it hopes to achieve. Thus the United States along with other nations today is properly concerned with problems of improving the environment in the years ahead. Environmental problems in the United States are by no means common throughout the country, just as these problems are not common among all nations. The United States, however, because of its extensive land and water area, and the great diversity of its economy, is experiencing differing degrees of pollution injury and environmental degradation.

Intensive industrialization has led to the development of urban centers with large population concentration, and thus resultant localization of pollution and environmental problems. Certainly pollution of the air has become primarily an urban problem. Although less localized, pollution of the water is also associated with a high degree of industrialization, urbanization and agricultural use.

Analysis of pollution problems can be approached in varying ways. For example, these problems are frequently divided into problems of air, water and land pollution. Another method is the analysis of the type of activity that causes pollution—such as industrial, agricultural, or general community activities. Most effectively, however, environmental conservation should be approached comprehensively by determining, on the most realistic basis, the environmental standards that need to be attained and maintained in order to provide for a satisfactory quality of life and work.

Thus environmental conservation involves the understanding and participation of all—government at every level, industry, academicians and scientists, and the public in general.

Today in the United States, one finds urban areas where pollution is seriously impairing the quality of the environment. On the other hand, there are rural areas where pollution is of little if any concern and where the natural environment shows minimum impairment.

Most peoples throughout the world, including Americans, have for some decades sought to improve the quality of life. And the manifest expectations of peoples in both developing and developed countries evidence no departure in that objective.

The United States through the operation of its free-enterprise competitive system has reached unprecedented standards of living. Not only has this system improved our own living standards, but it has also made great contributions to economic development throughout the Free World. The United States through both its private and public sectors continues to assist the Free World's developing nations to enhance economic development and standards of life.

Thus during the decades of the 1950's and 1960's, policy and effort have been largely directed to securing economic gains and it is only lately that acute concern has come to be directed increasingly to pollution control and environmental conservation. Indeed, only in recent years have information about and evidence of potentially serious pollution come to the attention of both the general public and the policy makers.

Today, society, including industries and governments, has a greater awareness that actions which are taken to raise living standards must be carried out, not only to meet adequately the needs of a rapidly expanding population, but also to maintain adequately the quality of the environment.

During the last 25 years, oil and gas have become the dominant fuels for the tremendous expansion of the U.S. economy. Oil and gas resources supply three-fourths of all U.S. energy requirements, with these resources continuing to supply the majority share of the energy market well into the decade of the 1980's. Industrial growth, upon which economic expansion is based, is directly dependent upon energy. With the world committed to economic growth there is thus an accompanying implicit commitment to increasing energy consumption. Also, economic growth is essential to provide the resources for societal objectives, including environmental conservation.

Principal sources of pollution are man and his activities, although nature also contributes. Comprehensive analysis of pollution and its causes would indicate that the operations of the U.S. oil and gas industries *per se* are responsible, relatively speaking, for a small proportion of the total, but the pollution generated by the use of petroleum products by both the public and private sectors of society is also important and the petroleum industry shares with society the responsibility to contribute to environmental improvements in these areas.

The U.S. petroleum industry has been concerned and will continue to be concerned with environmental conservation. For the future, its efforts are being strengthened to assure that its operations and products meet the requirements of our society both for energy and for environmental conservation. Of course, there will be costs associated with greater emphasis upon conservation of our environment both in the petroleum industry and in other sectors of our society. Since in the last analysis the complex American society is itself the collective source of man's pollution, these costs must be shared by all of us who will share in the benefits of an improved environment.

The National Petroleum Council has identified and addressed itself in this report to the environmental issues which it believes to be of concern to the oil and gas industries as well as to the nation. For presentation of key conclusions and recommendations, the issues have been grouped into the categories of general law and regulatory policy, the economics of environmental conservation, and specific environmental concerns for air, water and land pollution.

Law and Regulatory Policy

1. The role of government should be to ascertain the effects of pollutants, prescribe workable standards of air, water and land quality to be maintained and, in general, to leave to private initiative the means whereby the standards will be achieved.

To attempt to specify the particular method by which these standards are to be achieved would materially lessen the likelihood that the optimum solutions for society would be reached. By specifying the quality standards to be achieved, government will encourage individual innovation, with "marketplace regulation," and thus tend to obtain the optimum environmental quality control for each dollar of investment or other expenditure, yet avoiding governmental discriminations among competing enterprises. Such an approach will maintain the benefits of an innovative and diverse free-enterprise approach.

As a case in point, the most significant changes during the past 25 years in gasoline quality—improvements in antiknock quality, improvement in control of volatility and decrease in sulfur content—have been the free, competitive response to meet the requirements of the increasingly efficient, high-compression engines developed for automobiles. In this regard, modification of gasoline, standing alone, is generally an ineffective way to reduce automobile emissions. Gasolines, however, have been modified so as to help maintain proper operation of emissions control devices and aid in reducing and minimizing emissions.

In the field of water pollution control, also, the degree to which law or regulation is truly effective depends on the extent to which the prescribed standards are workable. For example, a definition of harmful quantities or qualities of oil discharge must necessarily be carefully drawn to permit timely yet practicable control.

2. Where a cooperative approach to the solution of an environmental problem would serve the public interest, the Executive Branch should clarify the extent of cooperation that is consistent with the intent of present antitrust laws and, if necessary, seek enactment of such further legislation as would be advisable to authorize the most effective means of dealing with such problems.

Our antitrust laws play a strong role in maintaining competition and diversity of effort that is most likely to produce the lowest cost solutions to meeting environmental standards. They properly prohibit conspiracy or collusive action by competitors in matters affecting commerce and public economic interests. However, to achieve the goal of improving the environment, in a few situations it may be that the best interests of society would be served if competitors or complementary industries were permitted to exchange information on a voluntary basis or jointly take actions regarding the modification of products or procedures in the public interest. For example, where environmental hazards exist, such cooperation may be the most feasible method to shorten the time for correction.

3. The United States should not pursue a policy of precluding or delaying exploration and development of the potential petroleum resources of its submerged continental margins.

Environmental quality control of the offshore petroleum provinces of the U.S., which are the prerogatives of the federal and concerned state governments, should be exercised effectively yet in such a way as to promote the exploration and development of these domestic reserves which are increasingly vital to the energy needs of the nation.

Several key points in this regard are:

- *Exploration and data-collection activities, which must precede drilling on the continental shelf, present no pollution hazard and should be continued without interruption in order to determine potential areas for drilling and production.*

  Adequate lead time and continuity of effort are essential to ensure efficiency and effectiveness in exploration for discovery of new reserves of oil and natural gas so that they will be available to the national economy and security when required.

- *It is a fundamental responsibility of government, after consultation with the petroleum industry, to update periodically the existing regulations for offshore drilling and production.*

  Rules and regulations under which the industry operates on the Outer Continental Shelf received considerable revision in 1969, with industry being given the opportunity to work closely, where appropriate, with the federal agencies in formulating these revisions. It is necessary that regulations keep pace with continually improving technology and procedures.

- *Undersea well completion technology is still in the early stage of development and techniques are not yet capable of being widely implemented. It would not presently be feasible and may never be desirable to require subsea completions as a matter of general policy.*

4. Conflicting jurisdiction and authority among and within governments with respect to offshore pollution hamper effective control and enforcement and should be effectively resolved.

Present laws divide jurisdiction and authority with respect to offshore spills between three federal agencies. States of the Union as well as other nations are also involved in this matter.

Economics of Environmental Conservation

5. The determination of environmental quality standards should, among other things, take into account the cost-benefit factor to society and the impact of that factor upon our economy.

Relevant inquiries in this connection are: *How clean? At what cost? With what benefit? How are these costs to be shared?* Costs and benefits to society of environmental quality control must be analyzed in the total context of losses and gains.

There are three basic costs involved in environmental conservation: (1) the cost of pollution reduction or elimination to prevent damage, (2) the cost of restoring environmental quality where damage has occurred, and (3) the societal cost associated with damage caused by pollution. The costs of restoring or preserving the quality of the environment in which we live, whether incurred by industry or government, are an expense of society and necessarily will be assumed by society in the form of increased taxes, decreased tax revenue through the extension of tax incentives, increased prices for goods and services, or in a combination of these. Abatement or restoration costs must be balanced against societal costs of damages from pollution so that the proper relationship between costs and benefits will be achieved.

The cost-benefit factor applies directly to many operations of the petroleum industry. Recognizing that its involvement in pollution control includes not only functional operations but also use of petroleum products, the petroleum industry has directed many millions of dollars toward control facilities and basic product research. These expenditures have increased from $271.4 million in 1966 to an estimated $559.5 million in 1970.

- *Severe, impractical or unnecessarily costly regulation of exploration, production and transportation reduces the incentives for proving and developing needed reserves of oil and gas and also increases the cost of petroleum products.*

- *Pollution control efforts will continue to have a major effect on capital spending and operating costs in refining operations of the industry.*

  It is difficult to determine cost alternatives in dealing with refinery waste problems, particularly because some facilities provide dual benefits in processing and pollution control. However, the ratio of capital costs for a high degree of treatment of waste waters to that of a low degree of treatment has been estimated to be almost 6 to 1. Furthermore, installing air pollution control equipment on existing refinery units is likely to cost from half again to double the amount for comparable equipment in new construction.

- *Other factors being equal, the benefits of economies of scale are just as applicable to petroleum operations as they are to other areas of the economy and ultimately result in cost savings to the consumer.*

  For example, large pipelines, huge marine tankers, and jumbo tank trucks and rail tank cars are now needed to transport crude oil, gas and other petroleum products used in the United States in order to meet the great demands. Indicative of the savings through increased size is an estimate that the transportation cost per barrel for a tanker run from the Gulf Coast to the New York City area is reduced by a factor of almost 3 for an increase in deadweight tonnage from 16,000 to 100,000.

- *Cost-effectiveness is the overriding consideration in reducing hydrocarbon emis-*

sions to atmosphere from storage and transportation of oil and gas.

Technology is available for almost any degree of control of such emissions. It is technologically possible but cost-effectively impracticable in some locations to eliminate entirely filling losses at service stations. Submerged fill pipes are a practical and economical means of reducing vapor losses from underground tanks.

6. *Where environmental quality does not meet prescribed standards, the constantly moving limits of technology and economics should be taken into account in setting realistic and stable timetables for achievement of the desired quality.*

Individual petroleum companies carry on intensive research programs to improve products and operations. The research effort alone of the petroleum companies relating to environmental conservation in 1970 is estimated to be almost one-third higher than the 1969 expenditures. This research effort has resulted in improved products causing less air and water pollution and improved operations minimizing all pollution.

There is an inevitable period of time involved in planning, financing and implementing measures, and in a number of instances for developing the necessary technology, to comply with prescribed environmental standards. Thus it is essential that, after standards are determined and the time period fixed for compliance, industry be able to rely upon the resulting schedule and not be subjected to continual and exceedingly costly schedule revisions.

In some instances technological advances may reach such a stage of development that they appear available for application in the very near future. If there is strong reason for confidence that such imminent technological advances will help to achieve pollution control objectives, then such technology should be awaited, provided this is in the general public interest.

These principles are applicable to several important areas of concern to the oil and gas industries today:

- *The effectiveness of control of oil discharges from offshore drilling and production operations can be continuously improved by the development of reasonable standards, together with time schedules in which to implement them, established by government with the advice of industry.*

  Oil discharges from offshore drilling and production operations have been a source of pollution. This can be controlled by proper procedures, equipment and treatment facilities, and efforts are continuing to ensure that this is done.

- *As the efforts of industry and government continue for effective offshore practices and regulations based on improved technology, every effort should be made by government to avoid the "stop-and-go" scheduling and cancellation of federal acreage sales.*

- *Technology and economics may lead to solution of the problem of sulfur dioxide emissions from petroleum fuels by the use of gas and low-sulfur fuels in small installations and residual fuels in large installations equipped with sulfur-control processes, such as stack-gas desulfurization when it becomes feasible.*

  Fuel desulfurization and lowered unit consumption in larger efficient installations are methods for reducing sulfur dioxide (SO_2) emissions with present technology; stack-gas desulfurization is not yet commercially feasible.

  The technology has not been developed for the removal of organic-type sulfur contained in coal. Low-sulfur coals, low-sulfur fuel oil and natural gas will have to be used to supply low-sulfur fuel demands until desulfurization of high-sulfur coals or removal of sulfur from stack gases becomes practicable. Currently, supplies of low-sulfur coals are limited to certain geographical areas and, as a result, fuel oil and natural gas will be used in a majority of new low-sulfur fuel markets.

7. *The inevitable costs associated with environmental conservation and pollution control must be borne by society. An approach is needed which will achieve environmental objectives at the lowest net cost to society and in a fashion which will maximize current benefits so that the costs incurred may be met on as current a basis as practicable.*

Costs of environmental conservation and pollution control could be met by utilization of one or a combination of methods, such as classifying environmental expenses as a normal cost of doing business, tax incentives, and/or government subsidies. Meeting environmental quality standards through market competition will provide the optimum quality for money expended.

A general tax credit for investment has been successfully used in the past as an efficient means for stimulating economic activity by encouraging the required investments. Such a tax incentive could be used to attain other objectives if there is a well-defined and practicable program at all government levels.

8. Imposition of economic penalties is not an effective means of attaining optimum environmental conservation.

As a general matter, genuine societal problems affecting the public welfare should be approached directly by the public and its government and not through indirect avenues such as governmentally-imposed economic penalties. As a practical matter, such economic penalties provide the option of meeting the imposed penalty and thus continuing the undesirable conduct without abating pollution. This approach also suffers from the virtual impossibility of selecting an equitable method of assessing charges for the vast number of potential pollutants.

This objection would be applicable to the imposition of charges on fuels as a means of controlling emissions into the atmosphere. In fact, this type of charge on fuel composition suffers from the further complication of selecting for assessment a particular aspect of the technical interrelationship between fuels on the one hand and, on the other, the vehicles or stationary plant for which they are designed. Such a charge would unnecessarily inject the government into the free-market competitive process, thus limiting the initiative of individual manufacturers to develop more effective means of emissions control. Proposals to apply charges to the sulfur content of heating fuels or to lead additives to gasoline might well, in practice, contribute nothing to environmental conservation and could even forestall progress now under way.

9. If required, regulations for the reduction of lead in gasoline should be planned realistically to provide for such reductions as are necessary to reach practical emission goals at a minimum overall cost to the public.

Regulations prescribing lead contents of gasoline are inappropriate and unnecessary. Low-lead and unleaded gasolines are now generally available and further restrictions on the use of lead will result in significant technical and economic effects on the production of gasoline. The use of lead alkyl additives in gasoline is by far the most economical method known to increase the octane quality of gasoline.

Specific Environmental Concerns

AIR

10. The most serious air pollution problem for the petroleum industry results from the use and, in some cases, the inefficient use of petroleum products to produce energy for our expanding standard of living and increasing population.

The emissions of main concern from mobile sources are hydrocarbons, carbon monoxide (CO), nitrogen oxides (NO_X) and particulate matter.

Reduction in local air quality can result from the use of petroleum products as well as any other fuel in fixed installations, such as fuel for power generation, manufacturing processes—including petroleum refineries, commercial and domestic heating, as well as from use of miscellaneous products such as solvents. Sulfur dioxide (SO_2) is primarily a result of the production of energy in various stationary sources. Small stationary energy-producing units also can produce significant quantities of unburned hydrocarbons and CO as a result of inefficient combustion and poorly maintained equipment.

11. Emissions from vehicles are a significant factor in air pollution in the United States.

The automobile has become a way of life in the United States. Almost half of the automobile travel is required for the purpose of earning a living.

The development and application of technology to reduce emissions from the internal combustion engine have been significant, and new technology will provide the essentially emission-free vehicle to conform with government goals. Hydrocarbon and carbon monoxide emissions from vehicles are trending down after having reached peaks in the 1965-68 period. Nitrogen oxides emissions will start down in 1973 and automotive particulates emissions will start down in 1976. The reciprocating engine with advanced emissions control systems will be the principal power unit for automobiles for the foreseeable future.

Natural gas and LP-gas (LPG) can be consumed in energy production with very low quantities of harmful emissions other than NO_X, but already-serious supply limitations and, in some instances, safety considerations will limit use of these fuels for vehicles.

12. Use of petroleum products is the source of only about one-fifth of the sulfur dioxide in the United States.

The petroleum industry has made substantial progress in lowering the sulfur content of its products. Since World War II, the already low sulfur content of the lighter liquid petroleum fuels—gasoline, diesel fuels and home heating oils—has been further reduced by more than 50 percent. Furthermore, progress is being made in reducing the sulfur content of residual fuel oils, although desulfurization of residual fuels significantly increases refining costs.

Stack-gas desulfurization is not expected to be a significant factor in reducing SO_2 from large electric power generating plants before late in this decade. These processes hold promise of enabling large fuel consumers to use high-sulfur fuels.

13. The amount of nitrogen oxides, carbon monoxide and hydrocarbons emitted from stationary sources is more dependent on furnace design and operating practices than on the fuel used.

All are amenable to control. New stationary installations are designed to produce low emissions. Old installations can be modified to reduce emissions.

Hydrocarbon emissions from petroleum-based solvents can be adequately controlled by incineration, adsorption or absorption if the process will allow adequate collection. However, some sources of hydrocarbon emissions, such as evaporation from newly applied paint or other architectural coatings, cannot be eliminated if a petroleum solvent is present.

14. Refinery air pollution control techniques have been developed which should permit refineries to operate in any community without constituting an area-wide environmental problem.

Progress has been made but continued efforts are required to achieve complete aesthetic and psychological acceptance by residential areas immediately adjacent to refineries. The major potential refinery emissions that may contribute to air pollution are sulfur compounds, nitrogen oxides, hydrocarbons, carbon monoxide and particulates including smoke. The methods and processes available for preventing the release of these substances in objectionable quantities are often very complex and expensive but reasonable air quality requirements can be, and generally are, met. Odors associated with even very minor amounts of certain compounds are perhaps the most perplexing problems.

15. Storage, transportation and marketing operations are essentially a closed system from source to customer; potential for air pollution exists at points of transfer and in abnormal occurrences.

16. Light and noise, although not normally categorized as forms of air pollution, are being controlled to an increasing extent at refineries.

During normal refinery operations the amount of gas burned in flares is, for conservation reasons, very small. However, at certain times, sudden increases have been the cause of complaints. It is therefore considered good policy to situate flares as well away as practicable from residential areas or other locations where they are exposed to the public, or to enclose the flares to reduce light emissions. Noise from refinery operations usually can be reduced by design changes in process equipment. Recognizing that both the public and governmental authorities have been increasingly concerned in recent years over intensified levels of noise from sources such as aircraft, highway traffic and industry, the petroleum industry will continue to be actively engaged in programs to reduce noise levels from refinery operations.

17. Petroleum industry research, on both a cooperative and an individual company basis, has led to an understanding of atmospheric chemistry and contributed to the development of technology for controlling emissions from both mobile and stationary sources.

The cooperative aspects of this research effort have been carried out in a variety of ways:

- The American Petroleum Institute has actively supported research on air pollution since 1953. This current broad research effort represents an expenditure of about $3.5 million a year in direct support of outside research efforts in addition to individual company expenditures and involves projects in both air and water conservation.

- The petroleum and automobile industries have worked cooperatively with the Federal Government through the Coordinating Research Council (CRC) and its Air Pollution Research Advisory Committee (APRAC) in developing technical information on the nature and effects of vehicle air pollution. The results of this research not only will aid industry to develop better controls for exhaust emissions but can also be an aid to the government in establishing realistic and practical air quality standards and emissions control requirements that are based on reliable technical information. The CRC program represents a research effort of $12 million over the past three years.
- Inter-industry sponsored research groups have contributed significant research results from extensive studies on the development of vehicle hardware and fuels required to meet the vehicle emissions goals and regulations. Much of the hardware now used on vehicles for emissions control was developed in these inter-industry (petroleum and automobile) research studies.

Within the framework of the antitrust laws, cooperative research by the petroleum industry will continue in the future with related industries and government. Major specific needs for such further research include:

- Health effects of emissions into the atmosphere
- Fuel-vehicle system to produce a "pollution-free car"
- Desulfurization of fuels and stack gases

18. Based on scientific studies, on a global aggregate basis air pollution is not a serious problem, although in many urban industrialized areas it has reached serious proportions. Studies involving international cooperation are needed to define any global effects of air pollution, particularly from man-made sources.

While man's contribution produces localized problems of varying degrees, depending on population density and natural ventilation, there is a question as to the effect of man's pollution on a global basis in view of nature's contribution and absorptive capability.

WATER AND LAND

19. Oil spills that occur during drilling and production operations offshore have resulted from uncontrollable natural causes or from accidents occasioned by equipment failure or human error. The potential hazard of such spills can be minimized but cannot be entirely eliminated.

The potential for pollution from such operations has been substantially reduced by sound practices, regulations and supervision.

An examination of the industry record offshore reveals that, despite the recent major oil spills during drilling and production processes, the petroleum industry has been highly successful in keeping serious pollution incidents at a low level during its history of operations in the offshore areas.

Safety and pollution control on offshore platforms are interdependent. Reasonable supervision of drilling operations, including ensuring the continual use of trained personnel and compliance with offshore drilling regulations, is imperative for safe operating practices and pollution control.

No oil spills of relative consequence have been associated with offshore pipelines. The potential hazard for accidental spillage from pipeline transportation of hydrocarbons offshore is somewhat greater than on land, but pipelines are the safest known method of transportation.

The greatest potential for water pollution from storage operations exists in offshore operations; pipeline transportation to shore reduces required storage volumes and therefore potential for large spills, but is not always economically feasible. Precautions are taken at terminals and bulk storage facilities to prevent oil pollution from surface runoff.

20. Although significant progress has been achieved by industry, even more advanced and more widely used standards, practices and facilities are needed for the prevention and control of oil spills from petroleum marine transportation and transfer operations—whether upon the high seas or upon U.S. coastal and inland waters.

The petroleum industry has taken positive steps for many years to improve technology and operational practices and to adopt the necessary standards so as to avoid oil spills from water transportation operations, but recognizes that oil on the ocean and coastal waters remains a major problem—one that is international in scope and requires the active participation of the petroleum industry for solution. At the same time, the problem encompasses all classes of ships, many of which are outside the petroleum industry's control, e.g., dry cargo vessels, government ships.

- *Where adequate facilities for disposal of oily wastes are not available, they must be provided at terminals, shipyards and marine facilities.*

  Although oil tankers are potentially a source of major oil pollution, there is no immunity from the threat of oil pollution from other types of vessels. The United States is subject to pollution to some extent from each of more than 5 million craft, including those on inland or intercoastal waters and those which call at U.S. ports in the process of carrying international commerce or for other purposes.

  Methods to ensure proper handling of all oily wastes should be established for all ships, regardless of ownership or registry. Without adherence to such methods and the availability of adequate disposal facilities, improper disposal will continue to cause pollution.

- *The prevention of major oil spills from mishap in tanker transportation of oil requires the continuing attention and cooperation of industry and government.*

  In the immediate areas affected, major oil spills from accidents with tanker transportation of oil are a serious pollution source for which the petroleum industry is developing solutions. Analysis of such mishaps during the period from 1956 to 1969 has provided relevant facts upon which to base actions to control this problem. For example, the most likely spill involved a tanker carrying crude or residual fuel oils and occurred within 25 miles of a port suitable for staging control action.

  Governments, as well as private industry, have a vital role in prevention of mishaps. Improved transportation support services, such as weather forecasting and navigational aids, and improved ship lanes would assist to minimize such accidents.

  Education and training requirements for ships' crews should be improved and geared to the size and design of the vessel. Increasingly coordinated efforts are needed between federal agencies and the shipping industry concerning marine operations and regulations. Efforts must continue through international organizations to improve international standards of vessel design and operation to prevent pollution.

21. *Specific well-staffed and well-equipped oil spill control centers are needed and should be established in strategic areas of high pollution potential.*

Methods of meeting this need are under study by the petroleum industry and substantial progress is being made in some geographical areas.

22. *Technology is not presently available to contain major oil spills under conditions of strong currents or heavy seas. Where conditions permit, containment and mechanical recovery of spilled oil often provide the most effective method of oil spill control.*

Little effective containment or recovery of spilled oil is possible today at sea where wave heights exceed 3 feet or surface currents exceed 1 knot.

However, at present, dispersing, sinking and burning offer possibilities for controlling major oil spills where their use is not prevented by other considerations.

Much research is needed on containment and recovery methods at sea and a considerable effort is under way. Current research efforts must be continued and additional funds allocated for oil spill control research efforts. This is an appropriate area for joint industry-government effort.

In addition to research efforts on containment and recovery of oil at sea, some other specific areas for research to improve control are:

- Methods of off-loading tankers at sea in an emergency situation.
- Methods of identifying oils, both in producing areas and in transportation, for proper identification of pollution sources.
- Definition and classification of oil-spill treating agents for both offshore and onshore, to provide guidance and safeguards in their use.
- Advanced techniques for rapid and efficient beach and shoreline cleanup, restoration of these areas, and methods of disposal of cleaned-up oil.

- Development of improved material specifications, testing procedures and instrumentation.
- The fate and behavior of oil on water and its true effect on the marine environment.

23. The preponderance of evidence does not support the thesis that permanent damage has been done to marine life and the environment by oil spills.

Oil spills are unsightly to the area where they occur and regrettably cause some mortality of certain marine invertebrates and birds. These disruptions of the ecology appear to be temporary, however, and the environments are restored in time. Further studies are being carried out in this important area.

24. The petroleum industry recognizes that refinery operations are a potential source of pollution and has taken positive steps for many years to reduce such pollution.

A petroleum refinery consists of a complex series of processes designed and operated to maximize the product yield from the crude oil utilized while minimizing the escape of hydrocarbons and other petroleum components.

Control is exercised over both water and airborne effluents, and precautions are taken to dispose of solid wastes in a manner acceptable to regulatory agencies. Nevertheless, more advanced and sophisticated environmental control equipment must be developed and placed in operation to keep ahead of societal demands.

The industry has, through its trade association, the American Petroleum Institute, made a comprehensive assessment of refinery effluent characteristics and waste-water quality control practices. Results of this survey are available to concerned government agencies for planning purposes.

Major aspects of the control problem are:

- *The nation's 281 refineries all have waste-water treating systems designed to handle various types of liquid and solid wastes.*

  Broadly speaking, most systems include in-plant control equipment, sewer systems and ancillary equipment for the collection and segregation of wastes, and gravity-type separators for the removal of oil and suspended solids. Many systems also include additional units for oil removal and/or some form of biological treatment. Facilities for the disposal of solid wastes and treatment of recovered oil are also important system features generally employed. Particular attention is usually given to reducing the oil content, suspended solids, oxygen demand, ammonia and phenolics content, and the taste and odor of refinery effluents.

- *Refineries require relatively large amounts of water for cooling, processing, steam generation, sanitation, and potable use, but much of it is furnished by recycling.*

  The freshwater intake of the refining industry has been reported to be only about 0.7 percent of total U.S. withdrawals and its consumption is only about 0.25 percent of total U.S. consumptive use. Ninety-seven percent of the total water requirement is for cooling. As water reuse, particularly for cooling purposes, continues to expand, raw water requirements per barrel of crude will, on the average, continue to decrease.

- *Advanced waste-water treatment processes are being developed and placed in operation at some refineries.*

  Various of these methods will be used more extensively as the degree of treatment needed to maintain proper quality of the receiving body of water increases. Chemical and physical monitoring of both refinery effluents and receiving water is commonly practiced.

25. Considering the volume of materials handled, land pipeline transportation of hydrocarbons is a minimal source of pollution.

It has been estimated that only six thousandths of one percent of liquids moved by pipeline per year was spilled, with the causes of most unrelated to daily oil industry operations.

26. Improper disposal of used lubricating oils and other wastes from marketing operations is a potential source of pollution, although not a major one at present because of industry efforts to assure proper disposal procedures.

As long as good housekeeping practices are followed, marketing operations pose little potential for pollution of land and water.

Summary Conclusion

It is the conclusion of the National Petroleum Council, an industry advisory body to the Secretary of the Interior representing virtually the entire American oil and gas industries, that these industries are conscious of their significant responsibilities for environmental conservation and are sincerely dedicated to a continuing and effective approach to the solutions to those environmental problems which lie within their purview.

The oil and gas industries are well aware of the environmental problems resulting from the conduct of their various operations of production, refining, storage, transportation and marketing of products, and also outside these industries, from the use of their products. Real progress has been made in defining these problems and developing solutions to them, but, nevertheless, problems remain. Continuing progress will be required to improve standards and to develop more advanced technology and better operating practices and equipment to achieve improved environmental quality.

The oil and gas industries face a requirement to provide to the society of which they are a part vital energy in a manner consistent with environmental conservation, recognizing that the costs involved are those of society. We are confident that these industries will continue to do their part, including full cooperation with government and with the general public which they serve, so that the requisite environmental standards can be developed and met, consistent with providing the nation with its necessary energy.

Part I

General Considerations

Chapter One

THE REQUIREMENTS FOR ENVIRONMENTAL CONSERVATION

Environmental conservation deserves the concentrated attention of all segments of society. A sharpened focus on problems of environmental quality by government, industry, the scientific community and the public indicates a growing realization that material well-being and a high standard of living based on continuous economic expansion cannot continue to be the overriding goal of society if severe environmental abuse is the result.

It is necessary to achieve a balance between the human need and desire for the products of science and technology provided by an industrialized society and the need for a wholesome environment. Society must continue to use the resources of the environment--there is no alternative. Responsible decisions will help to resolve conflicting interests and achieve the necessary balance.

To some extent, our environment can be permitted to absorb the wastes of civilization and nature without harm. Such absorption reduces the cost to society of disposing of wastes in other ways. However, if the waste load imposed on the environment is so great as to endanger the ecology or human health, or if it unreasonably interferes with other beneficial uses society wishes to make of its air, water or land, then further pollution control becomes essential. Environmental control also becomes desirable when the penalties to society from pollution are greater than the cost of correction. The problem lies in measuring values.

All members of the petroleum industry are becoming aware that economic solutions to problems are no longer meeting the standards set by society. While continuing to fulfill their primary mission of supplying energy to the Nation, the oil and gas industries have made a substantial increase in their commitment to environmental conservation.

This chapter examines research and data regarding source, effects and fate of pollutants as they relate to the oil and gas industries. It also reviews the requirements for and supply of energy, and the costs of environmental quality which must be considered in arriving at balanced and realistic programs for the attainment of environmental objectives. More detailed analyses of these factors pertaining to industry operations and to use of their products are included in subsequent chapters.

Section 1.
POLLUTION--NATURAL AND MAN-MADE

Both nature and man contaminate the environment. For example, nature's additions may result from volcanic action, forest fires, nitrogen fixation by lightning, dust storms and simple organic decay which may cause large additions of solids or gases to the atmosphere. Man's contributions to air pollution may be aerosols such as smoke, cement dust, cracking-catalyst fines or lead from automobile exhaust. They may also take the form of gaseous compounds of sulfur and nitrogen, carbon monoxide or hydrocarbons from fossil-fuel use.

Nature contributes to the contamination of water and land through such widely diverse forms as debris and suspended particulates swept into streams by storms, crude oil seepages from its natural entrapment below the surface, and vast amounts of animal wastes. In addition, man litters the landscape with discarded trash, pours inadequately treated human wastes into receiving waters and releases industrial materials and products in undesirable quantities--whether by accident, inadequate attention to controls, or as the result of carelessness.

Since man and nature continually add contaminants to the global system, there is a need to define acceptable standards of air, water and land quality to meet public concern and provide realistic and achievable base points for industry and community action. The members of the petroleum industry have gone on record as actively supporting efforts to conserve and wherever needed to improve the quality of the Nation's environment.

Subjectively it can be said that pollution exists as long as any appreciable segment of society is dissatisfied with some part of the environment. For example, it would be agreed that pollution exists when the health of the public is endangered; when there are gross malodors or obvious soiling; or when a user of air, water or land detracts materially from the usefulness of the environment by changing its physical and chemical characteristics.

Perhaps the greatest motivating force behind the public's concern for present environmental quality is an awareness that past trends seem to indicate that the future will be much worse. The public is rightfully concerned about the multitude of predictions that are being made today concerning the inability of the earth to sustain life in the future. Although these predictions are without a sound basis, their very existence causes a feeling of uncertainty about the future. On the other hand, the technological advances that have been made in the very recent past and the progress that is being made in the control of air and water quality point to improvement rather than further degradation.

Other significant factors of public concern are the general projections indicating increasing population and the growing concentration of population in urban areas. Although short-term trends indicate a slowing of the population growth, pollution concerns in areas of heavy urban concentration represent a problem that will not be solved overnight.

This report is concerned with major pollutants that may occur as the result of operations of the oil and gas industries--exploration, drilling, production, transportation, refining and marketing--and of the use of their products in mobile or stationary sources as indicated in Table 1.

Some of these pollutants are most likely to be found in high concentration and are more likely to cause significant harm in areas of high urban population. Most of them also occur in nature as products of oxidation and natural liquids. Others are localized industrial wastes which may be found either in urban or non-urban areas, depending on the location of the industrial operation. Thus the type of source, its location and the mechanisms of nature are all important factors in judging the need and manner of control.

A. The Urban Environment

In order to consider the environmental problem, it is necessary not only to identify the principal pollutants but also to consider their relative importance in the ecosystem. Pollution by man in urban areas may vary due to factors such as climate, geography, industrial development, utilization of fuels for transportation and energy, and refuse disposal procedures. Nevertheless it remains a significant problem.

In the United States over half of the people occupy less than 1 percent of the land. The urban problem is further compounded by the ever-growing amount of waste produced by both individuals and corporate citizens. Some types of waste production (for example, solid wastes) are increasing at a faster rate than the population as a whole.

The deterioration of the urban environment is not confined to the United States alone. Major cities around the world suffer from many pollution problems caused by the tremendous concentrations of human life and activity in such areas. Although urban pollution is a worldwide problem, it must be considered in terms of its locality. While man is in no real or immediate danger of seriously contaminating the earth's supply of air, water or land, he often overreaches the ability of a local stream or airshed to absorb wastes. Environ-

TABLE 1

MAJOR POLLUTANTS OF U.S. OIL AND GAS INDUSTRIES

Substance	Sources Use of Products	Sources Industry Operations
Air		
Sulfur Oxides	Stationary combustion sources	Refining
Hydrogen Sulfide		Production, transportation and storage, drilling, refining
Carbon Monoxide	Vehicles, stationary combustion sources	Refining
Nitrogen Oxides	Vehicles, stationary combustion sources	Refining
Particulate Matter	Vehicles, stationary combus- sources	Refining
Hydrocarbons	Vehicles, stationary combus- sources	Petroleum transportation and storage, marketing, drilling, production, gas treating, refining
Water		
Oil	Petroleum handling	Drilling, production, transportation and storage, refining, marketing
Drilling Mud and Treating Fluids		Drilling and completion
Brine		Production
Organic Compounds (Amines, Phenolics, Sulfides, Mercaptans)		Refining
Suspended Particulate Matter		Refining
Spent Caustics		Refining
Nutrients		Refining
Used or Waste Oil	Vehicles, industrial use	
Land		
Oil	Industrial use	Drilling, production, transportation and storage, refining, marketing
Brine		Production
Waste Water		Production
Sludges		Refining, production, marketing
Trash and Litter	All	All

mental difficulties of today's cities are further compounded by the lack of open spaces and parks, faltering transportation systems, substandard housing, poor sanitation, periodic power shortages, and the crush of too many people and inadequate services.

A prime example of the problem is New York City--an area with the most dense population of any American city and facing some of the worst urban environmental problems in the Nation. The streets are littered, the air is frequently overburdened with waste, and the rivers that flow by the city are polluted. Not far from the Manhattan area, however, there is fresh air, clean water and beautiful natural settings, indicating that the oft-spoken view that pollution is closing in on all sides is not necessarily true. The predominant existence of relatively unpolluted areas does not, however, lessen the effects of pollution on the urban and, to a growing extent, suburban dweller.

Aesthetically, the costs of pollution are apparent; the side effects on physical and mental health are more difficult to assess. Beaches may be closed to swimmers because the water is contaminated. Air pollution, at the very least, may aggravate developing respiratory disease. Garbage in the streets attracts rats and breeds disease. And a cacophony of sounds assaults the eardrums and the privacy of the city dweller, possibly also contributing to mental stress.

During periods of rapid economic, technologic and population growth in the past, relatively little concern was given to the environment. Cities, and then suburbs, grew almost at random, with little long-range planning. While society was concentrating on expanding its mode of living and on producing material goods and services, disposal of the waste products that were generated in the process was not adequately considered. Now they are too obvious to ignore.

Knowledge of the effects of pollutants is not complete, but it is known that these effects are not uniform in all urban areas. Acute toxicological effects of high concentrations of some air contaminants upon humans are well known, but even after years of investigation, the effects of exposure to low concentrations of the individual pollutants and mixtures thereof are still not conclusively known. Eye irritation and perhaps increased stress on those with serious respiratory ailments such as emphysema can be recognized on those exposed to high oxidant levels such as occur in a Los Angeles smog.

The effects of carbon monoxide and sulfur dioxide on humans remain under intensive study.[1] The concept of the constant body equilibrium with the particulate lead (intake equal to elimination) by Robert A. Kehoe[2] and the information gained from monitoring of the U.S. population[3] would tend to show that long-term adverse health effects are improbable. (More will be said concerning lead in later chapters.)

While vegetation damage has been shown in the laboratory with low levels of pollutants and such photochemical reaction products as ozone and peroxyacyl nitrates,[4] correlation with damage in the field has been difficult to substantiate and also requires further study.[5] One such project is being sponsored at Stanford Research Institute (SRI) by the Coordinating Research Council (CRC).[6] Its objective is the determination of the economic damage of air pollution upon vegetation in the United States.

The soiling effects of smoke on buildings and clothing, the effects of acid mist on fabrics, and the corrosion of metal and carbonate stone by acid pollutants are well known. As particulate and sulfur dioxide standards come into effect in all large urban areas classed under the air quality control regions by the Environmental Protection Agency (EPA), urban air quality should materially improve.

Odors and haze formation produce psychological but nonetheless real effects on urban residents. Such effects must be overcome and certainly point to the need for additional studies in aerosol formation and in photochemistry of the atmosphere. Several projects in these areas are being sponsored by CRC, as well as others (see especially p. 36).

Water and land pollution are also generally most acute in densely settled sections. Spillage of crude oil or petroleum products in or adjacent to these densely populated areas is understandably high on the list of the public's pollution concerns.

Overcoming the pollution ailments of our urban environment requires recognition of the interrelationships between the many problems of the urban community, and the cooperation of every segment of society, including government and industry as well as each individual. Governments have the responsibility of developing effective policies and standards as well as the means for their administration. Industry must adjust its operations and develop its products to meet urban environmental needs, as well as to accomplish its primary purposes. Every urban dweller must be made aware of the environmental consequences of his actions. Improving the urban environment may require completely new approaches, as well as rational judgment, to avoid curing one problem and creating another. For example, action to reduce air pollution by shifting from fossil fuels to nuclear fuels for power plants may lead to adverse thermal pollution of streams or high costs and delays in availability of needed power. A careful systems analysis must be made of all relevant variables to prevent wasteful and possibly seriously inadequate stopgap measures.

In the long run, our cities may require fundamental changes. The application of pollution control technology alone may not be enough to cope with some urban environmental problems, and entirely new concepts for cities may be necessary. For example, if population continues to increase, decentralization of population and industry may become necessary to make better use of available land and air space.

1. Air Pollutants

a) Sulfur Dioxide

The petroleum industry has demonstrated its ability to reduce the sulfur content of its fuels. For those areas dependent primarily on liquid fuels for energy, confidence is justified that sulfur dioxide from petroleum products will continue to decrease as required to achieve acceptable ambient sulfur dioxide levels. For large combustion processes using those fossil fuels which are not amenable to desulfurization, confidence seems justified that flue-gas desulfurization technology being developed will bring these sources under control.

b) Carbon Monoxide

Carbon monoxide is another pollutant for which there is considerable concern. The major combustion source is the gasoline engine, although lesser amounts of carbon monoxide are produced by other combustion sources.

As in the case of sulfur compounds, the problem with carbon monoxide is control to the point where health-damaging concentrations are not encountered in urban atmospheres. Recent improvements in carbon monoxide control on automobile exhausts and the confidence being evidenced by automobile makers that they can make further substantial reductions indicate that within the next decade this pollutant will be brought under control.

Careful studies by petroleum industry scientists have shown that while the number of automobiles has increased, total emissions in general (and carbon monoxide and hydrocarbons in particular) from the U.S. automotive population are decreasing, principally because of the installation of exhause controls. Confidence would therefore seem to be justified that carbon monoxide in urban atmospheres will continue to decrease as improved technology leads to lower emissions from automobiles and as earlier models without exhaust controls are retired. Despite the retirement of these earlier models, long-range control of exhaust emissions will require the application of improved technology and continuing maintenance of control devices which have been installed.

c) Nitrogen Oxides

Nitrogen oxides are of concern in certain urban situations where photochemical smog develops. High-temperature combustion processes contribute to their formation by fixation of nitrogen and oxygen atoms. About half the man-made nitrogen oxides emitted in the United States are from stationary-combustion sources and about half are from the automobile internal-combustion engine.

Recently developed technology indicates that, through exhaust gas recycling, sufficient reductions in emitted nitrogen oxides from automobile exhausts can be achieved to start concentrations in urban atmospheres from this source on a downward trend.

Laboratory tests indicate that catalysts can be developed which will reduce a major part of the remaining nitrogen oxides in auto exhausts to elemental nitrogen and oxygen. There seems to be complete justification for assuming that technology, going hand-in-hand with regulation, will bring emissions of nitrogen oxides from the automotive engine under control.

Emissions from stationary sources are also worthy of attention. The development of technology in this area is in its early stages. However, two-stage boiler combustion resulting in lower peak temperatures, and low excess air combustion making less elemental nitrogen available for fixation are known techniques for major reductions in nitrogen oxide emissions. Flue-gas recycling has also been shown to be technically feasible for control of nitrogen oxides with home heating oil, and work is under way at the present time to investigate the effectiveness of this technique in controlling nitrogen oxides produced by the combustion of residual fuel oils.

The development and application of technology provide a basis for encouragement that nitrogen oxide pollutants will be adequately controlled, even in urban areas. Therefore, health-endangering or visibility-reducing concentrations of nitrogen oxides need not occur in many urban communities. Further, where nitrogen oxide concentrations are a problem at the present, they will be reduced to acceptable levels.

d) Gaseous Hydrocarbons

Gaseous hydrocarbons may enter the urban atmosphere either as evaporatives from liquid hydrocarbons or as escaping gases in their normal state. The most important emissions take place during use of the products as a fuel, either because of incomplete combustion or because of evaporation in the combustion system. Some emissions may also occur as a result of use of industrial organic solvents.

The amount of hydrocarbon emissions from automobiles has already been reduced substantially. Reduction is particularly important because of the role played by hydrocarbons in the complex photochemical smog reaction.

Since hydrocarbons are products of the petroleum industry, control measures to prevent their loss during normal industry operations are customarily accepted as good practice for economic reasons as well as to ensure the proper atmospheric quality.

e) Particulates

Smoke and particulate matter are basically urban problems. However, with the application of known technology, precipitators, cyclones, baghouses and other techniques are now available for 90- to 99-percent control of most particulate emissions. The problem does not lie with the development of technology, but only in the reasonable setting and application of standards by governments so as to bring particulate emissions under control at a rate that can be met by the economy. It appears that the future can be viewed as one in which particulate emissions will be reduced until they are no longer a major source of concern. Although relatively little is known about the effects of submicron particles on humans, investigations are under way to determine their effects, if any, so that any needed action may be taken.

2. Water Pollutants

Spillage of liquid hydrocarbons may occur from several types of operations of the petroleum industry. Marketing is done in all urban areas, while transportation activities, refining and even production may be accomplished in or near urban areas, depending on the locale. In each type of operation, the magnitude, the nature of the problems and the solutions vary widely. Over the years, pollution from the normal operations of production, refining and transportation has been drastically reduced and work is continuing to accomplish further improvements. The petroleum industry is aware of the problems of spillage of hydrocarbons and disposal of waste oils and has initiated action designed to cope with these problems. These problems also require the attention of individual users of fuels and lubricants.

Technology is generally available for reducing water pollution to an acceptable level. Most research is aimed at improving the cost-effectiveness of wastewater treatment methods and related processes.

B. Global Source and Fate

As has been previously stated, man and nature add concentrations of their products to the world's environment--air, water and land--in varying degrees. On a global basis, man's contributions of a given class of air pollutants may be overshadowed by nature's, and the mechanisms of nature are quite capable of rendering harmless the cumulative contributions from both of them. Studies involving international cooperation are needed to define any global effects of air and water pollution, particularly from man-made sources.

1. Air Pollution

The global source and fate of atmospheric trace gases, which are the same as those produced from operations of the petroleum industry and use of its products, have been studied carefully. Eminent scientists E. Robinson and R. C. Robbins of SRI have, for example, estimated that the nitrogen compounds (oxides and ammonia) enter the atmosphere from nature at 1,838 x 10^6 tons per year, while man's contribution is only 57 x 10^6 tons per year. Table 2 presents a summary for a number of pollutants prepared by Robinson and Robbins in their careful study of the sources, abundance and fate of air pollutants.[7] As indicated in this table, man's activities appear to account for all of the sulfur dioxide and most of the carbon monoxide entering the atmosphere.

The basic concept developed by C. E. Junge,[8] Robinson and Robbins, and others is that for every pollutant entering the atmosphere, there is some mechanism in nature for its removal. Sulfur compounds are converted to the sulfate, and the nitrogen oxides to the nitrate, whereupon these materials held as aerosols are washed from the skies by rain or precipitate as dust. The cycle for movement of the nitrogen-containing compounds is shown in Figure 1. Similar diagrams may be prepared for other atmospheric pollutants.

Even for carbon monoxide, for which Table 2 indicates no known sink for its removal from the atmosphere, unpublished results from a CRC project at SRI indicate that great quantities of carbon monoxide are consumed by soil bacteria. Although not noted in Table 2, there are indications from other sources that ocean and bacterial degradation may be producing quantities of carbon monoxide in nature heretofore unrecognized.[9]

On a long-term global basis, it may be concluded from studies such as the one by Robinson and Robbins that for the more reactive pollutants--nitrogen oxide, nitrogen dioxide, sulfur oxide, hydrogen sulfide, and even carbon monoxide--concentration increases appear unlikely. Carbon dioxide concentrations do appear to be increasing for reasons not well understood, and continued and careful research appears justified.[10] Aerosols in the atmosphere are of concern also where the earth's weather and heat balance are involved.[11]

In order to examine the roles of man and nature further, we will consider in greater detail, for each of the major pollutants, emissions which are made by man, emissions by nature and the cleansing mechanisms of nature.

a) Sulfur Dioxide

The American Association for the Advancement of Science (AAAS) report, *Air Conservation,* estimates global production of sulfur dioxide as approximately 80 million tons a year.[12] The SRI report, previously mentioned, estimates 146 million tons a year. The AAAS report points out that, if their total estimated amount of sulfur dioxide were to remain in the air and be distributed evenly over the globe, the increase per year would be 0.006 parts per million. However, sulfur dioxide does not remain in the air. Responsible estimates are that it will last an average of 43 days and probably less (e.g., the Robinson and Robbins report estimates only 4 days).

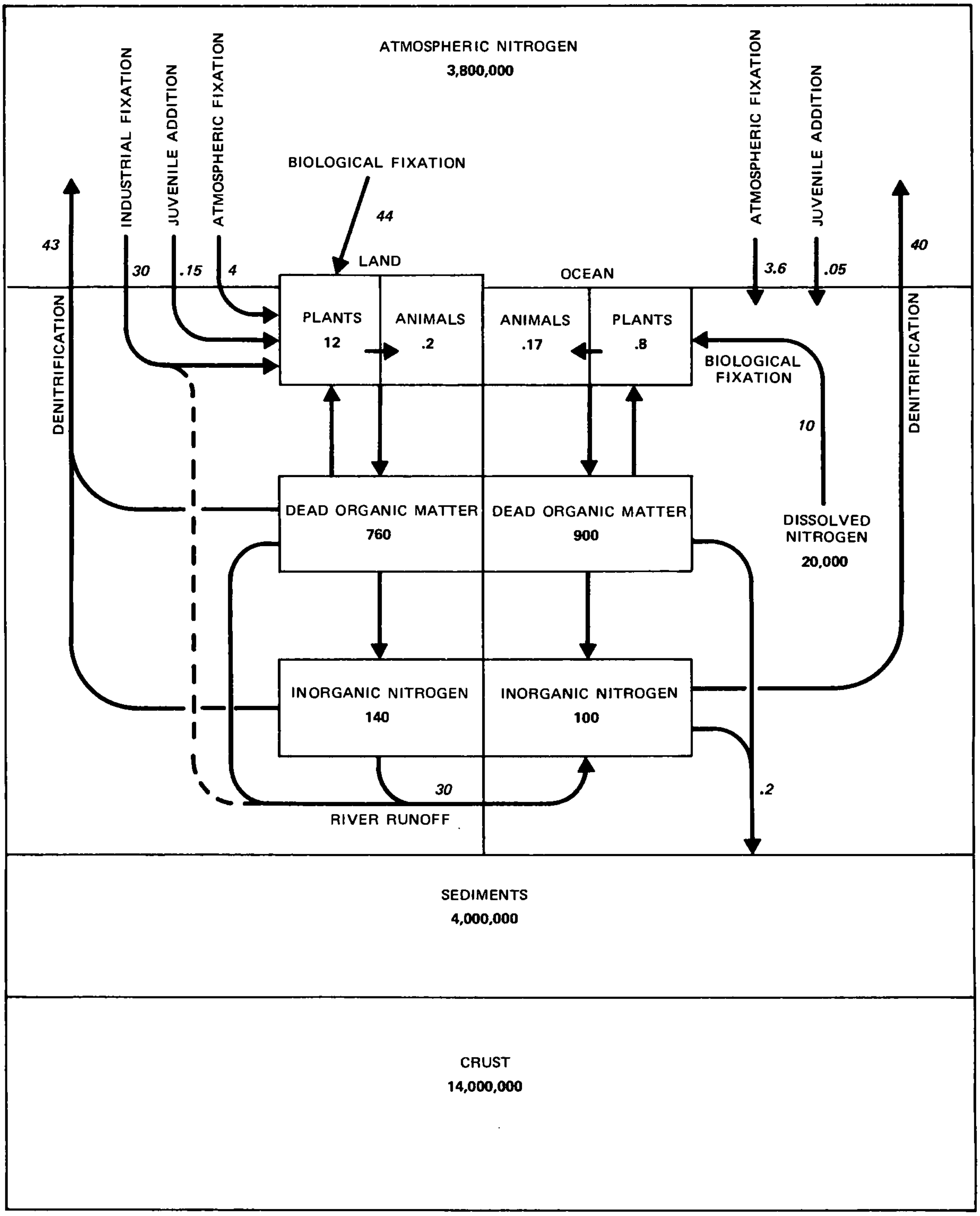
Sulfur dioxide is known to oxidize to sulfur trioxide, eventually forming sulfuric acid mist. The sulfuric acid then reacts with other materials in the air and forms, among other things, ammonium and calcium sulfate. Available evi-

TABLE 2

SUMMARY OF SOURCES, CONCENTRATIONS AND MAJOR REACTIONS OF ATMOSPHERIC TRACE GASES--JUNE 1969

Contaminant	Major Pollution Sources	Natural Sources	Estimated Emissions		Atmospheric Background Concentrations	Calculated Atmospheric Residence Time	Removal Reactions and Sinks	Principal References	Remarks
			Pollution	Natural					
SO_2	Combustion of coal and oil	Volcanoes	146 x 10^6 tons	None	0.2 ppb	4 days	Oxidation to sulfate by ozone, or after absorption, by solid and liquid aerosols	Eriksson (1959, 1960, 1963) Junge (1963) Lodge and Pate (1966)	Photochemical oxidation with NO_2 and HC may be needed to give rapid transformation of SO_2-SO_4
H_2S	Chemical processes, sewage treatment	Volcanoes, biological action in swamp areas	3 x 10^6 tons	100 x 10^6 tons	0.2 ppb	2 days	Oxidation to SO_2	Junge (1963) Smith et al. (1961)	Only one set of background concentrations available
CO	Auto exhaust and other combustion	Forest fires	275 x 10^6 tons	75 x 10^6 tons	0.1 ppm	<3 yrs.	None known, but large sink necessary	Bates and Witherspoon (1952) Robinson, Robbins (1968, 1969)	Ocean contributions to natural source probably low
NO NO_2	Combustion	Bacterial action in soil (?)	53 x 10^6 tons	NO: 430 x 10^6 tons NO_2: 658 x 10^6 tons	NO: 0.2-2 ppb NO_2: 0.5-4 ppb	5 days	Oxidation to nitrate after sorption by solid and liquid aerosols, hydrocarbon photochemical reactions	Junge (1963) Leighton (1961) Lodge and Pate (1966) Ripperton et al. (1968)	Very little work done on natural processes
NH_3	Waste treatment	Biological decay	4 x 10^6 tons	1,160 x 10^6 tons	6 ppb to 20 ppb	7 days	Reaction with SO_2 to form $(NH_4)_2SO_4$, oxidation to nitrate	Eriksson (1952) Georgii (1963) Junge (1963) Lodge and Pate (1966)	No quantitative rate data on oxidation of NH_3 to NO_3, which seems to be dominant process in atmosphere
N_2O	None	Biological action in soil	None	590 x 10^6 tons	0.25 ppm	4 yrs.	Photo dissociation in stratosphere, biological action in soil	Bates and Hays (1967)	No information on proposed absorption of N_2O by vegetation
Hydrocarbons	Combustion exhaust, chemical processes	Biological processes	88 x 10^6 tons	180 x 10^6 tons	CH_4: 1.5 ppm non CH_4: <1 ppb	16 yrs. (CH_4)	Photochemical reaction with NO/NO_2, O_3; large sink necessary for CH_4	Bates and Witherspoon (1952) Ehhalt (1967) Kovama (1963) Cavanagh et al. (1969)	"Reactive" hydrocarbon emissions from pollution = 27 x 10^6 tons
CO_2	Combustion	Biological decay release from oceans	1.4 x 10^{10} tons	10^{12} tons	320 ppm	2-4 yrs.	Biological absorption and photosynthesis, absorption in oceans	Revelle (1965) Keeling Bolin and Eriksson (1959)	Atmospheric concentrations increasing by 0.7 ppm per year

Source: E. Robinson and R. C. Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants Supplement*, prepared for the American Petroleum Institute by the Stanford Research Institute (Menlo Park, California, April 1971).



DISTRIBUTION OF NITROGEN in the biosphere and annual transfer rates can be estimated only within broad limits. The two quantities known with high confidence are the amount of nitrogen in the atmosphere and the rate of industrial fixation. The apparent precision in the other figures shown here reflects chiefly an effort to preserve indicated or probable ratios among different inventories. Thus the figures for atmospheric fixation and biological fixation in the oceans could well be off by a factor of 10. The figures for inventories are given in billions of metric tons; the figures for transfer rates *(italics)* are given in millions of metric tons. Because of the extensive use of industrially fixed nitrogen the amount of nitrogen available to land plants may significantly exceed the nitrogen returned to the atmosphere by denitrifying bacteria in the soil. A portion of this excess fixed nitrogen is ultimately washed into the sea but it is not included in the figure shown for river runoff. Similarly, the value for oceanic denitrification is no more than a rough estimate that is based on the assumption that the nitrogen cycle was in overall balance before man's intervention. From C. C. Delwiche, "The Nitrogen Cycle," *Scientific American*. Copyright © September 1970 by Scientific American, Inc. (p. 140). All rights reserved.

Figure 1. Distribution of Nitrogen.

dence suggests that a substantial amount of atmospheric sulfur dioxide is neutralized directly by ammonia, calcite dust or other airborne alkalis and is then oxidized to corresponding sulfates. Precipitation in the form of rain or snow eventually removes these salts from the air. These factors have led the AAAS report to state, "Sulfur oxides may, therefore, be of little global concern from a long-range point of view."[13]

All the other sulfur compounds which might be considered as pollutants, such as hydrogen sulfide and mercaptans, are converted by direct and photochemical oxidation to sulfate and are washed from the air. It has been estimated that as much as 75 percent of the total airborne sulfur may enter the atmosphere as hydrogen sulfide from natural sources, but these sources are so diffused and the lifetime of the hydrogen sulfide in the air is so short that perceptible concentrations are seldom encountered.

Therefore, it appears that as far as sulfur compounds are concerned, if man can control their occurrence in crowded urban centers so that they do not cause unwanted effects before they are diffused in the atmosphere, then we should have no present need for action concerning their global effects, other than continued study.

b) Carbon Monoxide

Estimated emissions of carbon monoxide on a worldwide basis total 275 million tons annually. The measured global concentration of carbon monoxide in the ambient air does not agree with the calculated amount of carbon monoxide which should be present, leading to the conclusion that there is an unknown sink for this pollutant. However, if the estimated annual production of carbon monoxide were evenly spread over the lower atmosphere, we would be encountering only a buildup of 0.03 parts per million carbon monoxide, which is not a cause for alarm. Some scientists believe that carbon monoxide is oxidized in the atmosphere, although slowly; however, accumulation seems improbable. As stated in the AAAS report, "there are no measurements of the rate of conversion of carbon monoxide to carbon dioxide, and it therefore cannot be stated with absolute certainty that there is no increase."[14]

c) Nitrogen Oxides

Even if all the produced nitrogen oxides were to remain in the air and be evenly distributed in the earth's atmosphere, then the increase per year would be 0.000002 parts per million. This amount in itself would appear to be insignificant. It is known, however, that oxygen in the atmosphere slowly reacts with nitrogen oxides, eventually forming nitrates that are slowly removed from the air by precipitation. Therefore, again it is concluded that control is needed only to keep nitrogen oxides below health-damaging and visibility-diminishing levels in urban atmospheres.

d) Particulates

It has been predicted that particulate matter will continue to increase in global air until the shielding effect on sunlight will cause a buildup in the polar ice caps, resulting in a modern ice age. At the same time it has been contended that the volcanic eruptions which cause a noticeable and immediate increase in global particulate levels are followed by 5-year average temperatures on the order of 0.1 degrees Fahrenheit lower than before the eruption occurred, after which no effect has been observed. It would appear, therefore, that the cleansing effect of precipitation is sufficient to prevent any material increase in the global concentration of particulates in the atmosphere.

Responsible estimates place man-made additions of particulates to the atmosphere at 800 million tons annually. This has been calculated to be about one-eighth of a cubic mile, or equivalent to a small volcano. Indications are, however, that we are in somewhat of a material balance, with the present rate of additions to the atmosphere being removed by nature's cleansing mechanisms.

e) Carbon Dioxide

Whereas carbon dioxide is not considered a threat to man's health or his comfort, there has been much discussion of its possible future effect upon global conditions.

Carbon dioxide is known to cause a greenhouse effect in which reflected sunlight is prevented from going back into outer space, leading to the hypothesis that increases in carbon dioxide, if they indeed do occur, could cause increases in the earth's temperature, leading to a melting of the ice caps and a flooding of the world's coastal areas. A study of this problem led the AAAS to view the problem first from its direct effect on man and secondly from its global implications. In its report, *Air Conservation*, the society stated, "Carbon dioxide is not normally considered an air pollutant because (i) the uncontaminated atmosphere has a concentration of approximately 300 ppm, (ii) it is essential for animal and plant life, and (iii) there must be at least 5000 ppm in the air before man's respiration is adversely affected."[15]

The amount of carbon dioxide produced by man's activity has been estimated to exceed 9 billion tons per year in recent times. However, about 2,300 billion tons of carbon dioxide are estimated to be present in the earth's atmosphere. The present concentration of carbon dioxide in ambient air is variously estimated to be from 320 parts per million to something in excess of 340 parts per million, and combustion processes now appear to be increasing this concentration about 1.6 parts per million per year. It therefore appears that within the visible future there is little possibility of carbon dioxide in the global atmosphere reaching levels which will have any effect on man's respiratory system.

The AAAS report, with respect to the global implications of carbon dioxide and the possibility of an increased greenhouse effect, declared:

> Some scientists believe that the slight rise of average temperature over the entire earth, which has been observed during recent decades, may be the result of the increase in atmospheric carbon dioxide.
>
> However, the hypothesis that an increase in carbon dioxide will increase global temperatures is by no means proved.[16]

Because of the unknown dependence of atmospheric water content on the temperature and the fact that global measurement of temperatures has not been going on for a sufficient length of time for an assumption to be made that the earth's temperature is either increasing or decreasing, the AAAS report goes on to state:

> In any cast, the fear seems legitimate that an unchecked increase in the rate of combustion of carbon fuels may eventually extend carbon dioxide levels to meteorological and physical significance, and that carbon dioxide concentrations may become great enough to cause climatic changes. If, at the end of this century, the average temperature has continued to rise and, in addition, measurement shows that the amount of atmospheric carbon dioxide has also increased, this will add validity to the idea that carbon dioxide is a determining factor in causing climatic change.
>
> Within a few centuries, man will be returning to the atmosphere and the oceans the concentrated organic carbon that has been stored in sedimentary geologic formations during hundreds of millions of years. If, by so doing, he finds that his climate is being altered in an undesirable way, he may be forced to turn to new sources of energy in order to reestablish a viable carbon dioxide equilibrium.[17]

In summary, considering all of the pollutants reviewed, we find that there are some uncertainties as we look to the future of ambient air quality on a global basis, but indications are that the urban air quality problem can be brough under control in a timely fashion. As far as global implications are concerned, it seems a justifiable conclusion that there will be no possibility of establishing whether or not a serious problem exists until at least the turn of the century. If indications at that time are that major changes are required, society can meet that requirement as it has met its challenges throughout history by developing alternative social or technological solutions.

2. Water and Land Pollution

Water and land pollution are most acute in densely settled sections. Spillage of crude oil or petroleum products in or adjacent to these densely populated areas is, therefore, a possible source of pollution, which is high on the list of public concerns.

A growing interest in the possible spread of land pollutants by underground waters has prompted investigations into this area. There has also developed a growing interest in the possibility that local pollution incidents may affect the ecological balances in bodies of water--from major lakes to the oceans of the world--because of accumulation of pollutants to an extent that they no longer can be tolerated by living organisms or altered by natural processes in the marine environment. These large bodies of water provide a common sink for a large variety and quantity of natural and man-made pollutants. Since the effects of oil spills on the waters are of direct interest to the petroleum industry, this section will review the effects and fate of such oil spills to the extent that they are presently known and understood.

Effects of oil spills on the environment have been examined by Dillingham Corporation by means, primarily, of review of reports and literature on past spills.[18] These effects were considered in two broad categories: (1) living resources including waterfowl, fisheries, the marine food chain and marine mammals, and (2) non-living resources, primarily land, and its use.

In addition, the geographic distribution of population and living and non-living resources in the coastal zone of the United States was considered. A generalized summary of the distribution of coastal zone population, parks and fisheries is presented in Figure 2. The concentration of coastal parks (which include many wildlife refuges and seashore recreation areas) and the nearshore fisheries is apparent.

With very few exceptions, adequate observation of the environmental conditions prior to a spill incident is generally lacking, so that an accurate assessment of the impact of a spill is extremely difficult. Thus, evaluation of the effects of oil spillage in most instances reflects only the obvious characteristics. Likewise, there has been insufficient monitoring of environmental recovery after the incident. Even so, on the basis of those situations for which data are available, recovery is generally complete and remarkably rapid.

a) Living Resources

The following section provides a discussion of the apparent effects of oil spillage on living resources (birds, shellfish, fish, food chain and marine mammals).

Marine birds, especially diving birds, appear to be the most vulnerable of the living resources to the effects of oil spillage. Harm to the birds from contact with oil is reported to be the result of a breaking down of the natural insulating oils and waxes shielding the birds from water and the loss of body heat. In addition, harm is also reported because of plumage damage and ingestion of oil or an oil/dispersant mixture. In addition, birds may be harmed indirectly through contamination of nesting grounds or through interruption of their food chain by destruction of marine life on which the birds feed.

The possible effects of the spillage on the bird population will vary with the season. For example, non-migratory birds will be the hardest hit with the pos-

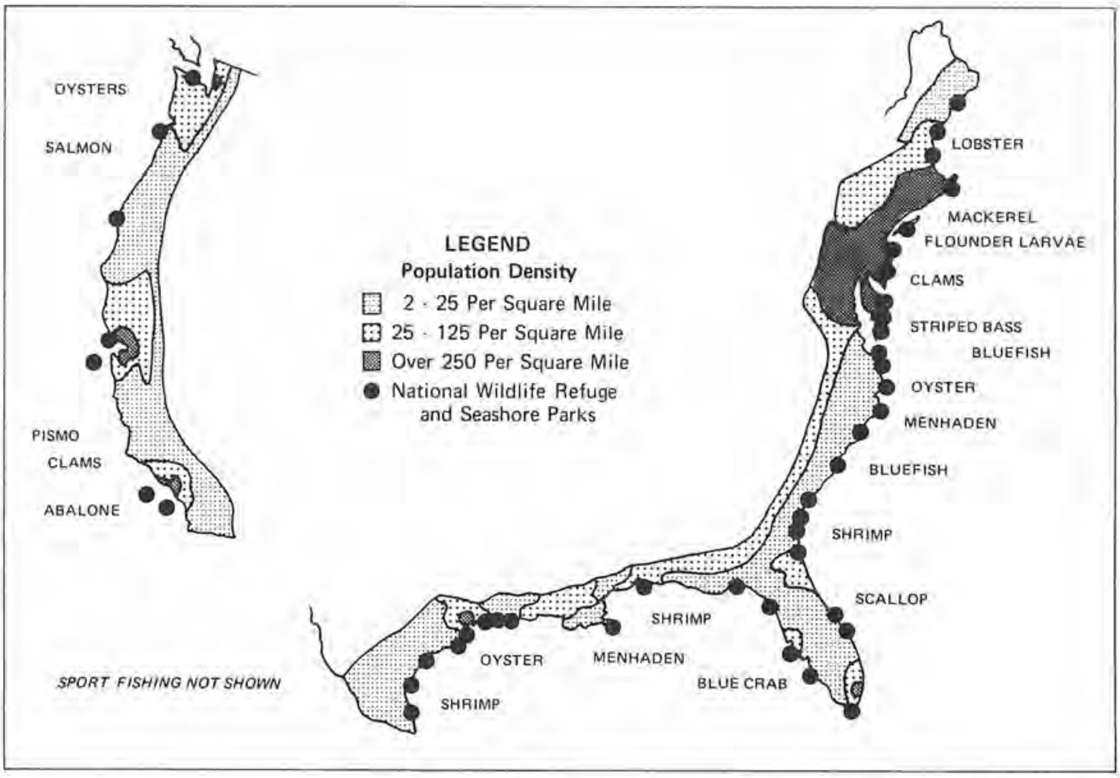


Figure 2. Population, Fisheries, and Parks in the Coastal Zone of the United States.

sibility of eliminating an entire colony. Young birds during the late nesting season and flightless adults during the moulting season may be particularly vulnerable along the shore. Conversely, various groups of migratory birds may avoid exposure because of their migratory patterns.

Although efforts to cleanse or rehabilitate contaminated birds have generally been unsuccessful, with less than 20 percent of the treated birds surviving, research in this area is continuing.

Along the coasts of the United States there are several areas where the bird population includes species whose existence could be threatened by a local oil spill. These include:

- The whooping crane at Aransas, Texas (about 50 individuals of this species exist; thus the entire species might be destroyed by contamination of their habitat)
- The brown pelican in Louisiana
- The Cape Sable seaside sparrow in southernmost Florida
- Eider ducks in Maine waters
- Alcids (auks, puffins, murres) in the Pacific Northwest.

Areas such as Aransas, Texas; Cape Sable, Florida; Brigantine, New Jersey; and Roosevelt, Long Island, have valued bird populations and are also closely associated with moderate to heavy tanker traffic.

The groups of marine birds most likely to be affected by an oil spill in the coastal waters of the United States are the diving birds, swimming birds and coastal wading birds.

Shellfish (including mollusks such as clams, oysters and scallops and crustaceans such as crabs, lobsters and shrimp) appear to be the marine life most directly affected by oil spillage in the coastal zone. Although the flavor of the flesh will be temporarily affected, most of these types will survive contamination by heavy oil alone. Lighter petroleum fractions (diesel or gasoline) are more likely to be fatal, and some species, such as razor clams, may experience significant mortalities. Shellfish appear to be quite vulnerable to the majority of chemical dispersants, and in past oil-spill incidents where heavy dispersant spraying has been conducted in the tidal zone or in shallow areas with restricted circulation, large shellfish kills resulted. Fortunately, the effects of oil spillage on shellfish appear to be fairly temporary, and even in those situations where high mortalities were observed at the time of the incident, complete recovery of the shellfish population appears to have taken place within a period of 6 months to 2 years.

Finfish generally appear to be unaffected by either the presence of spilled oil or the dispersed mixture of oil and chemical treatment materials. This is probably due to the rapid dilution of the contaminants in the deeper water away from the shoreline and to the mobility of the fish permitting them to avoid areas with high oil or chemical concentrations. Danger to fish is probably limited to possible harm to eggs, larvae or juveniles which seasonally may be found concentrated in the upper water layers or in shallow areas near the shore.

The effects of oil spillage on the marine food chain or food web (which consists of plants, bacteria and small marine organisms) are not well understood because of the wide fluctuations and cycles that occur naturally and are totally independent of the effects of oil. Lower marine plants appear to be fairly tolerant to contamination by oil and oil/dispersant mixtures and, where destruction has taken place, have repopulated rapidly, although in proportions varying from original numbers. Some forms of algae and diatoms appear to be stimulated in growth by a certain amount of oil. Various bacterial organisms will also feed on available oil and multiply, thus providing energy to the protozoan level of the food chain. In general, oil spillage and cleanup methods do not appear to have lasting effects on the food elements of the marine environment.

Relatively few observations of any direct effect of oil spills on larger marine mammals such as whales, seals and sea lions have been made. These animals appear to be able to sense and avoid oil on the surface of the water, and various accounts of oil-covered animals do not appear to be substantiated. Possible effects to young or disabled mammals are viewed as being comparable to normally occurring mortalities, and spilled oil is generally considered to result in minimal harm to marine animals.

b) Non-Living Resources

The effects of oil spillage on the non-living resources of the environment are generally linked to the use of the land, the water and the air contaminated by the oil or by the control methods employed to clean up the oil. Direct damage caused by the oil is usually limited and of a temporary nature in that natural dissipation of the oil and cleanup of the environment will occur with time. Where the land and waters are in regular use, such as in harbors and marinas and for water sports or on beaches, or where personal property such as boats or docks are affected, then a more rapid and thorough cleanup is required to minimize the damages resulting from loss of use of these facilities.

With the increasing concentration of population along the coastlines of the United States and the reservation of much of the remaining coastal areas for parks and wildlife refuges (see Figure 2), there are few places where oil spillage on the coast can be permitted to dissipate naturally. With this in mind, efforts to avoid coastal contamination following an oil spill should be comparable to the effort required to clean the coastline should oil come ashore.

Considering the effect of oil cleanup methods on non-living resources, the most noticeable result appears to be the use of improper methods or treatments which cause a further distribution of the oil or oil residue. For example, heavy spraying of detergents on oil-contaminated beaches may result in the oil sinking into the beach. An over-corrective cleanup may cause the loss of beach sand, surfaces on walls and rocks, and painted finishes; attempts to remove oil by burning may result in temporary air pollution.

c) Regional Effects

Summarizing, the effects of an oil spill on the environment appear to be most significant with regard to seabirds and their habitats. Also affected at times are shellfish beds, inshore spawning areas and high-use coastal property. The ecological effects appear to be temporary, with the possible exception of loss of bird life. Efforts to avoid oil contamination of coastal areas should take particular care to protect those resources most susceptible to damage.

Damage to the environment from oil-spill control or cleanup operations appears to be limited to marine life in the intertidal zone and to be linked primarily to the possible detrimental effects of improper use of chemicals.

A detailed survey and plot of the living and non-living resources likely to be affected by an oil spill in a particular geographic region would be of great assistance in planning oil-spill control action for that region.

d) Global Problems

The Massachusetts Institute of Technology recently sponsored a Study of Critical Environmental Problems (SCEP)[19] in which the following were considered to be worthy of discussion insofar as their possible effects on the water environment were concerned:

- DDT
- Mercury and other toxic heavy metals
- Nutrients
- Wastes from nuclear energy
- Oil in the ocean.

It is interesting to note the study's conclusion that very little is known about the effects of oil in the oceans on marine life and the recommendation that much more extensive research is required to determine such effects. The petroleum industry, government agencies and others, including distinguished scientists at eminent oceanographic institutions, have conducted and are continuing to conduct studies of oil-spill prevention and control.

Section 2.
BALANCING BASIC NEEDS

At certain points in time, society reaches an expressed or implied common consensus as to the values it wishes to maximize or goals it hopes to achieve. During the period since the economic depression of the 1930's and World War II, our society has sought to maximize economic goals so that the American economy would provide increasing material benefits to all Americans. During this period, through the mutual effort of the private sector and the government, ever-increasing numbers of the American people have come to enjoy improved living standards.

The tremendous economic expansion that has taken place in this country during the 25 years since the end of World War II has depended on energy supplied increasingly by petroleum. There is a direct relationship between the requirement for energy and the degree of industrialization. Thus, as industrialization becomes more intensive, the need for energy grows rapidly.

Having achieved impressive economic gains in recent decades, the United States along with other nations is reexamining its priorities. Greater emphasis is being placed on the conservation of the natural environment in which we live. At the same time, continued economic growth is necessary in order to achieve all of our Nation's needs, including the adequacy of the environment.

In the early part of this century, neither the number of people nor the degree of industrialization was such as to cause major concern about our environment. In fact, there was very little information available upon which to base an appreciation of the potential impact of these factors upon the environment. Science has not only made possible the technological development that raises living standards, but is also providing knowledge which allows an insight into the effects of these developments upon our environment. As our knowledge has grown, it has become apparent that, to achieve higher standards of living through scientific and technological applications, these two lines of endeavor must also be used to prevent a severe deterioration of our life-sustaining environment that could indeed be self-defeating.

In the current process of harmonizing values, there is an inevitable cost to be paid in balancing the need for conservation of our environment with our energy requirements. And since our complex society is itself a collective polluter of our environment, the expenditures necessary to maintain satisfactory environmental quality must be viewed as societal costs.

The cause/effect relationship in national energy and environmental conservation matters must be anticipated by government policy-makers. Further, in determining reasonable standards of environmental quality and the time period required to reach them, government should carefully take into account, after consultation with the private sector, the cost-benefit factor and its impact upon the economy. Since environmental circumstances differ dramatically from place to place, these standards cannot and should not be expected to be reached in unreasonably short time periods, nor will they be attained uniformly throughout this country or internationally.

A highly industrialized society such as ours cannot exist without intensive utilization of natural resources. But wise management and broader acceptance of the multiple-use principle make it possible to develop the most effective means of utilizing these resources. Thus, differing interests in the environment can be reconciled and a proper use balance can be achieved, a balance that is in the best interest of society as a whole.

A. The Need for Energy

1. United States Energy Requirements

U.S. energy requirements are projected to continue to increase, responding to the needs of a complex, industrial-based society whose members generally enjoy high and rising living standards. The major purpose of this analysis is to bring out the fact that the Nation has increasing future requirements for energy and the various aspects of energy so that a perspective may be established of the relationship of energy to standards of environmental conservation.

In the more distant future--1980 and beyond--forecasters tend to differ more widely in their estimates of both population and economic growth. Since U.S. energy requirements are closely correlated with both population and economic trends as well as with society's changing characteristics, the range of energy demand forecasts for the later years of this century similarly tends to widen.

Energy demand growth usually is underestimated; each succeeding forecast, public and private, tends to be higher than its predecessor. Present (1970) estimates by oil companies and others reflect the continuation of this phenomenon, although each forecast is analyzed carefully by its maker in the light of existing conditions and expected change before release (see Table 3).

TABLE 3

REPRESENTATIVE ENERGY DEMAND PROJECTIONS TO 1980 TRENDS IN SUCCEEDING FORECASTS
(In Quadrillion BTU's)

	Date of Preparation of Estimate		
	1968	1969	1970
Bureau of Mines "Medium"*	88.1		
Chase Manhattan Bank	97.6		108.5
Marathon Oil Company	92.2		101.7
Texas Eastern	97.8		
Arthur D. Little		99.3	
Oil & Gas Journal		101.7	
Shell Oil Company		103.0	
Stanford Research Institute		100.0	
Continental Oil Company			102.4
Gulf Oil Corporation			100.0
Humble Oil Company			105.7
Mobil Oil Corporation			98.9
Standard Oil Company (Indiana)			107.6
AVERAGE	93.9	101.0	103.5

* Bureau of Mines range was 73.9 to 104.7 quadrillion BTU's in its 1968 estimate.

In 1968, the Bureau of Mines projected "medium"* 1980 U.S. energy demand at 88 quadrillion BTU's† (41 million barrels daily expressed in oil equivalents).[20] This projection represented a 3-percent growth rate from 62 quadrillion BTU's (29 million barrels daily oil equivalent) in 1968. Currently, however, most forecasters expect U.S. energy demand to total more than 100 quadrillion BTU's in 1980 for an average annual growth of at least 4 percent above the 69 quadrillion BTU's recorded in 1970.

These growth rates can be compared to the average energy demand growth of 3 percent experienced since World War II. The higher expected rates are due largely to rapidly expanding use of electric power, where energy input exceeds

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*In the Bureau of Mines study, the "medium" represents "a medium-range level of demand for total energy and its components to the year 1980, calculated by relating these to the projected trends of a number of relevant determining variables."

†One quadrillion (10^{15}) British thermal units equals about 470,000 barrels daily crude oil equivalent.

output by about three to one. In addition, future gains are anticipated for petrochemical feedstocks and other non-fuel uses of petroleum, which are included within the broad category of "energy requirements." Generally, per capita energy consumption should increase at a faster pace in future years, with population growth increasing at a relatively slow rate, some continued improvement in energy fuel use efficiency, and a considerable increase in the use of energy for environmental controls.

The implications of steadily rising long-term forecasts of energy requirements, and the wide variations between different forecasts made concurrently, are so great that several detailed studies are now under way to examine the possibilities in depth. The National Petroleum Council is currently evaluating the U.S. energy supply/demand outlook to the year 2000, with the expectation that its final report to the Secretary of the Interior will be complete in mid-1972.[21]

a) Energy Markets*

The U.S. industrial sector comprised the largest market for primary energy resources in 1970, followed by (in descending order) electric utilities, transportation, residential/commercial and non-fuel raw materials. By 1980 each is projected to consume more energy, with electric utilities projected to exhibit the most rapid growth and become the largest market. The growth in electric utility demand is expected to result from the developing trend towards replacement of fossil fuels in residential/commercial and industrial markets with purchased electricity. Transportation is expected to gain second place by the year 1980, the gap between it and utilities being partly a function of the extent to which mass transportation displaces other modes such as automobiles, trucks and planes, which may be used as individual transportation.

b) Interfuel Competition

Interfuel competition for the foreseeable future is expected to be influenced by the degree to which society emphasizes environmental quality. Although comparative prices remain a major determinant of energy market share between various fuels, the elements of cleanliness, convenience, availability and efficiency in use are becoming increasingly important. There seems little doubt that "degree of cleanliness" has become a particularly significant factor in consumer decisions.

No real interfuel competition exists in today's transportation market, and little reason exists for expecting significant changes in the basic technological, economic and demographic factors behind the consumption of these fuels. A major displacement of petroleum in transportation seems unlikely in the foreseeable future since it would require either an economic breakthrough or enormous social and political pressures to implement.

There is presently a small but expanding market for petroleum as the basic raw material for products other than energy fuels. It is anticipated that this market, particularly for chemical products, will involve little interfuel competition.

Interfuel competition is, however, highly intense in the residential/commercial and industrial markets. Once dominated by coal, these markets were increasingly acquired by oil, then by natural gas after World War II. Today, oil and gas are encountering strong competition from a secondary energy source, electricity.

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*For purposes of analysis, markets for energy resources are divided into:

Industrial (e.g., manufacturing, industrial processes, etc.)
Transportation
Electric Utilities
Residential/Commercial
Raw Material and Other (essentially non-energy use of energy resources)

Fuels for electric utilities themselves represent a highly competitive arena, with the fossil fuels competing with each other and, increasingly, with nuclear fuels. Through 1980, the use of low-sulfur fuel oil in the electric utility market is expected to increase in relation to coal and gas, while non-breeder nuclear fission may not attain formerly expected prominence. However, the purpose of this section is to provide a perspective of the relationship between growing energy demand and environmental conservation, rather than to examine the energy outlook for the future.

c) Demand for Oil

The 1968 Bureau of Mines "medium" projection of liquid hydrocarbons demand in 1980 was 18.2 million barrels daily, and their highest estimate was 21.6 million barrels daily. Currently, oil industry observers would agree that the "high" projection appears low, considering an expected average annual growth rate of about 4 percent annually over the 14.7 million barrels daily recorded in 1970. This compares to an average growth of 4.7 percent annually since World War II. Table 36 (p. 270) gives an historical breakdown of U.S. domestic petroleum demand through 1970. A recent projection for the years 1975 and 1980 by the Oil Demand Task Group of the National Petroleum Council projects a demand in 1980 of 22.3 million barrels daily under the assumptions that there will be minimal changes from present government policies, practices and economic climate (Table 4).

TABLE 4

U.S. PETROLEUM DEMAND BY PRODUCT
(Million B/D)

	1975	1980
Motor Gasoline	6.9	8.2
Kerosine Jet	1.2	1.7
Distillate	2.9	3.4
Residual Fuel Oil	3.1	3.8
Other	4.2	5.2
TOTAL	18.3	22.3

Source: NPC, *U.S. Energy Outlook--An Initial Appraisal 1970-1985* (July 1971), p. 24.

The major transportation fuels (primarily gasoline and jet and diesel fuel) will exhibit rapid growth through the 1970's, assuming no significant displacement of oil-fueled vehicles. Demand for light and heavy fuel oils is expected to show competitive vigor throughout the 1970's due to rising supply costs for coal and natural gas, limited availability of natural gas and severe sulfur restrictions--factors of particular importance to the large utility and industrial customer. Feedstocks for the chemical industry will be another growth product.

d) Demand for Natural Gas

Projected natural gas requirements--estimated independent of supply limitations--would indicate greater expansion than previously estimated. In a 1969 report by the Future Requirements Agency (FRA), natural gas demand (including field use) is forecast to increase from 21.5 trillion cubic feet (TCF) in 1968 to 34.7 TCF in 1980, a 4.1-percent compounded annual growth over that period.[22] Commercial and industrial uses (including interruptible) were expected to increase more rapidly than residential, the other major gas-consuming area.

As noted earlier, the FRA projection assumes an adequate supply of gas for all markets and a continuation of present-day interfuel relationship trends. Therefore, these figures merely quantify a widely shared opinion that potential demand could not be totally satisfied because supply capability would be lacking under current regulatory practices and economic conditions. Under these circumstances, actual demand for gas would be curtailed by limited supply.

2. United States Energy Supplies

The long-term stability of petroleum supplies in meeting the Nation's diverse needs appears to be a policy objective of the Federal Government. To achieve this desirable goal it then becomes imperative that the Government adopt wise, firm and predictable long-range policies for environmental quality that are consistent with this objective.

In 1970 the United States produced almost 90 percent of its overall energy requirements, importing the balance in the form of oil, natural gas and liquefied natural gas (LNG). There is little doubt, however, that rapid depletion of proved domestic reserves of oil and gas--unless countered by policies that provide a favorable climate in which the industry can increase domestic exploration and production--will lead to sharply increased dependence on imports. In this regard, it should be noted that the number of exploratory wells drilled in 1970 was the lowest in 22 years. A myriad of political, social, technological and economic factors will interact in shaping the Nation's future energy supply environment, with security of supply increasingly a paramount issue.

a) Oil and Gas Supplies

In recent years, new reserves of oil and gas have not been added to the U.S. energy inventory in sufficient volumes to offset production (see Table 5).

Both newly discovered Alaskan oil and gas reserves and the reserve potential offshore of our Nation are apparently large. Furthermore, a recent report of the National Petroleum Council indicates a major untapped potential within the contiguous states of the United States.[23] However, it has become evident that considerably more extensive exploration and development will be required to assure a reasonable degree of domestic self-sufficiency, and that a continuing large financial commitment must be made. In 1969, for example, the major oil companies directed $3.9 billion to exploration and development costs in the United States.[24] To an increasing extent, therefore, national oil policy must be concerned with this need. Further, normal operations to explore for reserves of oil and gas do not contribute a pollution hazard, and although a threat of pollution from spilled petroleum does exist in development and production operations, the probability of such pollution is extremely small and has been continually reduced through improved technology (see Industry Operations, Chapters Three through Eight).

Concern is also being expressed about future natural gas availability. This is best illustrated by quoting from a recent Federal Power Commission (FPC) report: "Evidence is mounting that the supply of natural gas is diminishing to critical levels in relation to demand."[25] Note also the trends in Table 5.

Dealing only with the short-term future, the FPC report concluded that the national reserves to production (R/P) ratio (excluding Alaska) will drop to 10.2 by the end of 1973 and that the U.S. gas industry and its customers will be increasingly dependent on supplementary sources of gas in the years beyond 1973. Supplementary sources would include Canadian imports, LNG imports by ocean tanker, Alaskan (North Slope) natural gas, and synthetic gas from coal.

TABLE 5

U.S. PROVED RESERVES OF OIL AND GAS

	Reserves at 12/31	Average Annual Additions	Average Annual Production	R/P* at 12/31
Crude Oil (Billion Barrels)				
1950	25.3			13.0
1960	31.6	3.0	2.4	12.8
1965	31.4	2.5	2.6	11.7
1970†	39.0	4.6	3.1	11.7
Natural Gas Liquids (Billion Barrels)				
1950	4.3			18.8
1960	6.8	0.6	0.3	15.8
1965	8.0	0.7	0.5	14.4
1970	7.7	0.6	0.7	10.3
Natural Gas (Trillion Cubic Feet)				
1950	184.6			26.9
1960	262.3	18.0	10.4	20.1
1965	286.5	19.3	14.6	17.6
1970†	290.7	20.3	19.6	13.2

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* The "Reserves-to-Production Ratio," i.e., year-end reserves divided by that year's production.

† 1970 year-end figures show an increase because they include reserves in the Prudhoe Bay Permo-Triassic reservoir on the North Slope of Alaska. These resources were discovered in 1968 but reported by the API and AGA for the first time on March 31, 1971, as proved reserves of 9.6 billion barrels of crude oil and 26.0 trillion cubic feet of natural gas, as of December 31, 1970.

Source: *Reserves of Crude Oil, Natural Gas Liquids, and Natural Gas in the U.S. and Canada and U.S. Productive Capacity as of December 31, 1969,* Vol. XXIV (May 1970), published jointly by the American Petroleum Institute, American Gas Association and Canadian Petroleum Association; American Petroleum Institute and American Gas Association, News Releases (March 31, 1971).

Thus, a high probability exists that some utility and industrial consumers will convert to other fuels. Currently, low-sulfur fuel oils appear to be the logical alternative.

Regulation of gas prices at the wellhead has tended to discourage exploration for natural gas supplies. Higher natural gas prices would undoubtedly help the reserves picture for this relatively pollution-free energy resource. Any additional gas supplies would also reduce the total expenditure needed to control pollution, because the alternatives--coal and fuel oil--contain varying amounts of sulfur which must be removed.

Oil shale and coal constitute an enormous domestic resource for energy and should become significant elements in the supply picture for liquid and gaseous hydrocarbons. However, for economic and technological reasons, they will probably not be a major factor in the overall supply of these hydrocarbons in the near future.

b) Coal Supply

U.S. coal resources are so large that sufficient demand could stimulate, in time, the necessary level of production. There are potential constraints, however, such as the rising costs associated with depletion of the most economical deep coal reserves and labor problems, which will act against a major resurgence in coal supply even if coal's environmental problems can be solved. Nuclear fuels and low-sulfur heavy fuel oil will tend to acquire an increasingly larger share of utility demand.

Table 6 illustrates a major dilemma in the coal supply picture: The largest resources are located in several western states, while demand has been concentrated in the eastern United States. Although generally of lower grade than eastern coals, western coals contain less sulfur. This advantage may be offset, however, by needs for land conservation measures associated with strip mining. Nevertheless, as the population and economies of western states expand, they are expected to produce greater amounts of coal, largely for generating electricity. With improvements in technology and the economics of long-distance, high-voltage transmission systems, mine-mouth power plants have an increasing potential. The generally higher-grade eastern and midwestern coals, becoming more expensive to mine and transport to market, will encounter growing competition in traditional utility and industrial markets.

TABLE 6

U.S. COAL RESOURCES AND PRODUCTION

	Resources* (Billion Tons, 1/1/67)	Production† (Million Tons)		
		1959	1969	Incr.
Appalachian	295	302	395	93
Mid-Continent	258	97	140	43
Rocky Mountains	870	13	25	12
West Coast	137	1	1	--
TOTAL	1,560	413	561	148

* Source: U.S. Geological Survey Bulletin 1275 (1969). Determined by mapping/exploration; all ranks; overburden 0 to 3,000 feet; about half are considered recoverable.

† Source: U.S. Bureau of Mines, *Minerals Yearbook*, 1959 and 1969 ed.; Weekly Coal Report No. 2766 (September 18, 1970).

On balance, coal resources represent an enormous potential supply of domestic hydrocarbons. But like domestic oil shales, dramatic growth in their utilization is heavily dependent on development of a substantial market from the production of synthetic oil and gas.

c) Synthetic Oil and Gas Supplies

One recent estimate of domestic synthetic oil potential, based on current technology, totals about 385 billion recoverable barrels.[26] However imprecise the estimate, these reserves (about 60 percent represented by coal) are many times the present proved reserves of conventional oil, but after many years of research and development and a considerable capital investment they are not yet commercially competitive as sources of liquid or gaseous fuels. Such synthetic fuels should become increasingly significant elements in the future supply picture. However, as generally projected, the economics of synthetic fuels indicate no domestic commercial production of synthetic oil earlier than 1980 and only relatively small amounts of synthetic gas. Many observers now believe, however, that national security considerations plus potentially improved economics will stimulate some development during the 1970's.

d) Nuclear Fuels

Estimated U.S. reserves of uranium oxide (U_3O_8) available at prices up to $10 per pound were 390,000 tons at the end of 1970.[27] Higher-cost resources considerably exceed this estimate. The Atomic Energy Commission (AEC) continues to anticipate that annual U.S. commercial requirements for uranium oxide will approach 35,000 tons in 1980--based on operating capacity of 150,000 megawatts in that year--and that cumulative requirements during the 1970's will approximate 200,000 tons. However, considering the continuing delays in installation and operation of nuclear power plants because of problems with siting, construction and environmental restrictions, the AEC demand estimates may be high.

Assuming the AEC projections are realized and that an 8-year forward ore reserve in 1980 will provide an adequate proved supply base, almost 300,000 tons (in round figures) of uranium oxide should be added to proved $10-per-pound U.S. reserves during the 1970's. This implied average gross discovery rate of 30,000 tons per year was exceeded several times during the 1950's and again starting in 1969, when incentives were attractive. Supply of domestic uranium oxide is therefore expected to be determined by economic rather than geologic considerations. However, there is an inevitable lag time between a resurgence of drilling effort and increases in reserves.

e) Other Energy Sources and Systems

Installed conventional hydroelectric capacity in the United States totaled 53,000 megawatts at year-end 1969, having doubled since 1956.[28] However, the domestic potential for conventional hydroelectric energy has been so extensively developed that few desirable sites remain unused. Therefore, steady but slow future growth is anticipated for such hydroelectric capacity, primarily in the Pacific Northwest region, with hydroelectric energy not maintaining its present proportion of electric power generation.

Other energy sources are constantly being investigated, and some--such as geothermal energy--are being actively developed. However, their potential for significant contribution to meet domestic energy needs is either small or unlikely to have any impact in the foreseeable future because of either technological or economic factors. Similarly, no early significant contribution is expected from the use of such energy conversion devices or systems as magnetohydrodynamics (MHD), fuel cells or nuclear fusion. Nevertheless, research into these and other areas is continuing amd may eventually produce a useful new source of energy. Nuclear fusion is now considered the most promising nonsolar source of man's energy needs for the distant future.

B. The Benefits and Costs of Degrees of Environmental Quality

The purpose of this section is to (1) develop a broad system of benefit classification and (2) illustrate generally the magnitude of costs related to those benefits. Later chapters will discuss more completely those benefits and costs specifically associated with air, water and land pollution control by the oil and gas industries.

1. Benefits

Some forms of pollution constitute hazards to the health of man, animals and plants. Similarly, often inseparable from health hazards, physical and mental irritants can downgrade the general well-being of living organisms. Finally, there are a variety of direct and indirect economic benefits that would result from reduction of pollution.

Some short- and long-run benefits from control of environmental pollution could be classified as follows:

- Physical Health
  - a) Reduced incidence of human disease
    - 1) Major--emphysema, typhoid
    - 2) Minor--common cold, dysentery

  b) Fewer diseases in animals/plants destined for human consumption

  c) Reduced effects on non-food animals/plants.

- Quality of Life
  a) Reduction in physical irritants--unpleasant odors, particulate matter, high noise levels

  b) Reduction in mental irritants--discolored foliage and art works, unsightly dumps

  c) Improved recreational facilities--beaches, parks

  d) Improved aesthetic qualities--tree-lined streets, clear skies.

- Economic
  a) Increased productivity from agriculture and industry

  b) Increased recreational opportunities

  c) Reduced corrosion

  d) Better utilization of raw materials.

Some of the above could be broadly quantified, but most--being intangible--cannot. As stated earlier, the degree of air, water or land "purity" required to achieve various benefit "levels" must be balanced against the impact of their attainment on other requirements of society.

Improvements will not be achieved quickly or uniformly around the Nation. A series of economic trade-offs must be made at local, state and national levels among these basic questions: *How clean? How soon? What benefit? What cost? Who pays what share of the costs?*

2. Costs

There are three basic costs involved in environmental conservation: (1) the cost of reducing or eliminating pollution before damage is done, (2) the cost of restoring environmental quality where damage has occurred, and (3) the societal cost associated with damage caused by pollution. Abatement or restoration costs must be balanced against societal costs of damages from pollution so that a proper relationship between costs and benefits will be achieved.

The costs of restoring or preserving the quality of the environment in which we live, whether incurred by industry or government, are costs of society in the final analysis and necessarily will be assumed by society in the form of higher taxes, inconvenience, higher prices for goods and services, or a combination of these.

a) Responsibility for Costs

The determination of environmental quality standards should also take into account the cost-benefit factor to society and the impact of that factor upon our economy. For example, severe, impractical or increasingly costly regulation of exploration, production and transportation operations of the petroleum industry reduces the incentives for processing and developing needed resources of oil and gas and also increases the cost of petroleum products. The effectiveness of environmental controls can be continuously improved by the development of reasonable standards, together with time schedules in which to implement them, established by government with the advice of industry.

Assigning responsibility for pollution damage or control costs is, of course, often a formidable task. In situations where the oil and gas industries have assumed sole or joint responsibility, costs can be related to mobile and stationary sources (automobiles, electric utilities) and to various operations (production, refining, transportation). Costs could be further classified as to where they are incurred in the stream from raw materials to point of final consumption. Some of the short- and long-run costs of pollution and its control are classified as follows:

- Cleanup/Repair Costs of Pollution Damage
  - a) Tangible
  - b) Intangible
- Costs of Pollution Control
  - a) Mobile Sources
    - 1) Responsibility of consumer
    - 2) Responsibility of vehicle manufacturer
    - 3) Responsibility of fuel producer
  - b) Stationary Sources
    - 1) Responsibility of fuel user
    - 2) Responsibility of fuel producer
  - c) Oil and Gas Operation
    - 1) Drilling and production
    - 2) Refining
    - 3) Storage and transportation
    - 4) Marketing

b) Magnitude of Costs

The total past and future costs of reducing or eliminating various types of air, water and land pollution are also unknown. However, major efforts have been undertaken by industry and government to evaluate required control costs at differing standards or levels.

The Department of Health, Education and Welfare (HEW), for example, identifies three basic costs associated with air pollution control: (1) the cost to consumers of reducing two types of polluting emissions from automobiles, (2) the cost to various industries of reducing sulfur oxides and particulate emissions from stationary sources, and (3) the cost to governments of eliminating stationary source emissions, plus research and development expenditures by the Air Pollution Control Office of the Environmental Protection Agency (EPA).[29] Summarized in Table 7, these three alone may require a total estimated annual expenditure of about $1.9 billion by 1974, depending on the degree of air pollutant reduction required. They do not include such related costs as the automobile industry expenditure to develop and produce emissions control devices, or oil company costs directed towards making fuels available at lower sulfur or lead content, which would raise the cost to over $2 billion.

Such cost figures can be misleading, as they fail to account for offsetting revenue which may result or for alternative possibilities. For example, elimination of sulfur oxides would bring some offsetting revenue from the sale of sulfur. An example of a major trade-off or compromise would be accepting lower performance in automobiles in return for a combination of engine design and fuel composition that would eliminate or greatly reduce polluting emissions.

Other compromises might be to accept the risk of greater dependence on a single energy source, such as electricity for home heating, in return for a shift of limited natural gas supplies to other markets to reduce air pollution, or accepting a greater risk of reliance on foreign petroleum sources in return for tighter controls on exploration and production in the United States for the purpose of pollution abatement. However, these latter compromises, while economic

TABLE 7

ESTIMATED COSTS OF CLEAN AIR CONTROL*
(In Millions of Dollars)

	1971	1974	Period Total
Automobiles	480.0	480.0	1,920.0
Stationary Sources			
Electric Power Plants	225.9	429.5	1,420.3
Sulfur Oxides	154.0	266.2	912.0
Particulates	71.9	163.3	508.3
Industrial Combustion	174.6	296.6	1,059.5
Sulfur Oxides	112.8	201.5	713.0
Particulates	61.8	95.1	346.5
Industrial Process	82.3	140.8	500.3
Sulfur Oxides	8.6	27.6	85.3
Particulates	73.7	113.2	415.0
Commercial			
Sulfur Oxides	54.5	75.5	273.5
Governments	207.4	454.5	1,281.2
Abatement Control	128.0	280.3	790.5
R&D	79.4	174.2	490.7
TOTAL COSTS	1,224.7	1,876.9	6,454.8

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* These are "high" costs associated with maximum control.

Source: HEW, *The Cost of Clean Air* (October 1969).

Note: The Council on Environmental Quality (CEQ) in its Second Annual Report (1971) to the President estimated cumulative U.S. environmental control costs for the 5-year period 1970-1975 will be $105.2 billion: $38 billion for water, $23.7 billion for air and $43.5 billion for solid wastes.

in a sense, also involve basic questions of national security and the ability of the American society to survive sudden and uncontrollable reductions in the availability of the energy resources on which this society has grown to depend.

No satisfactory answer exists as to total tangible costs of pollution damage borne by the oil, gas or other industries, or by property owners. Obviously, the intangible costs, such as long-run health damage and physical irritants, are even less amenable to computation.

Published tangible costs of major oil spills are illustrative. For example: The Santa Barbara oil leak cost the companies involved about $5 million in cleanup expense; the *Torrey Canyon* accident cost several insurance companies about $7.3 million in claims by countries and individuals. No one knows the derived costs from these incidents (such as higher insurance premiums, etc.). Some are publicly reported; many go unrecorded. Moreover, tangible damage costs can be associated with natural events like oil seeps or ascribed to carry-over effects of historical events such as the sinking of a very large number of oil tankers off the shore of the United States during World War II.

Therefore, some caution should be used when considering various figures purported to be all-inclusive costs of pollution damage. The $11 billion annual figure frequently cited for annual air pollution damage, for example, apparently is a simple extrapolation from local data gathered in Pittsburgh in 1913.[30] Other often-quoted estimates like the $500 million annual damage to crops may also be difficult to support.[31]

Since no method is yet suitable for estimating tangible and intangible pollution damage costs, any attempt to provide a total dollar figure would be misleading at this time. It should be sufficient to note that from society's viewpoint, these costs are large and apparently rising with increasing industrialization and urbanization.

c) Petroleum Industry Conservation Actions

The U.S. oil and gas industries, recognizing that their involvement in conservation includes not only functional operations but also the various aspects of consumer use of petroleum products, have directed many millions of dollars toward control facilities and basic product research. Based on a conservatively structured survey made under the auspices of the American Petroleum Institute (API), it has been estimated that $271 million was expended in 1966 and that this annual amount has risen steadily to the point where it has reached an estimated $560 million in 1970.[32] This represents a combined total of more than $2 billion during the 5-year period and a rate of spending in 1970 of more than $1.5 million daily on air and water conservation. It may be noted that these sharply increased conservation expenditures came at the very time that business profits generally declined.

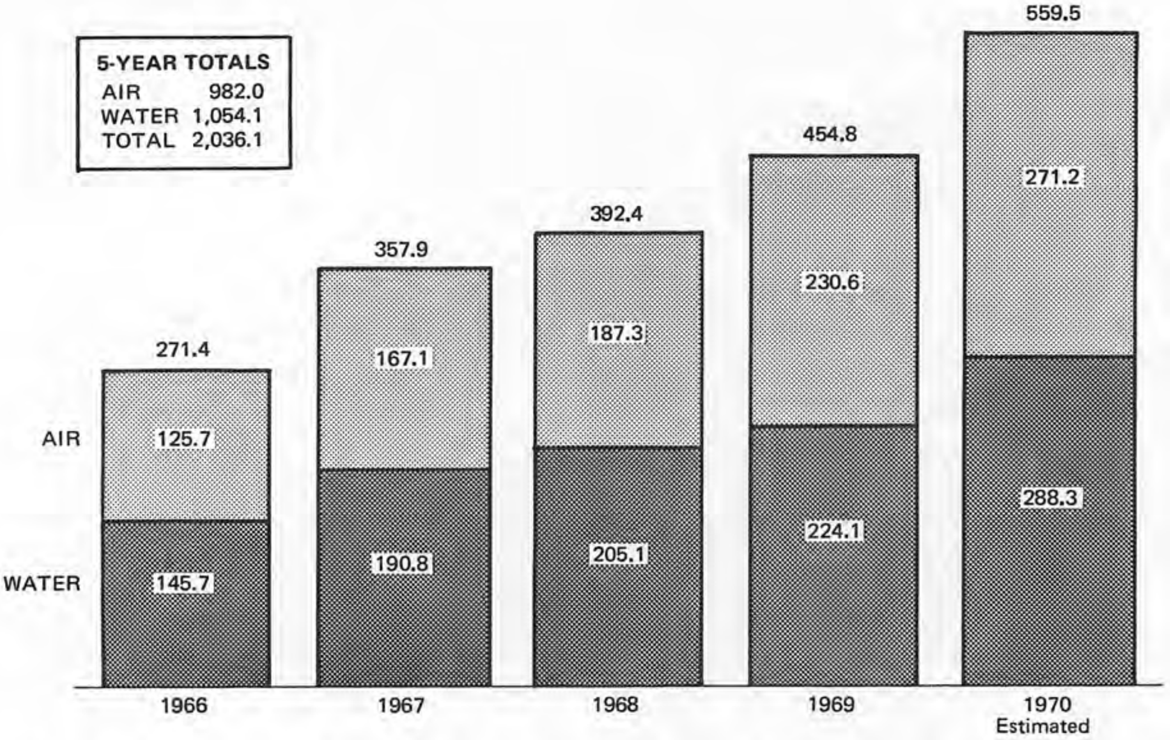
In addition, it should be noted that the combined 5-year expenditure data cover only what the oil companies spent within the United States. For example, heavy investments made in the Caribbean and elsewhere to provide low-sulfur fuel oils--most of which are consumed in the northeastern states--were not included in the survey findings.

Figures 3 and 4 indicate the distribution of expenditures between air and water pollution control. Total conservation expenditures for air and water have been essentially in balance over the past 5 years, while research and development expenditures have been heavily weighted toward learning more about air pollution and ways to control it.

Expenditures for water and air conservation measures have been heavily on capital equipment, a considerable investment from which no profit return can be expected. These expenditures have been largely to control air and water pollution in refining facilities and for water conservation in the production of crude oil and gas. Included were funds for electrostatic precipitators in refineries. These items may cost more than $1.5 million apiece and an average refinery would need several. Cyclone air cleaners for a single refinery cracking unit cost more than $500,000.

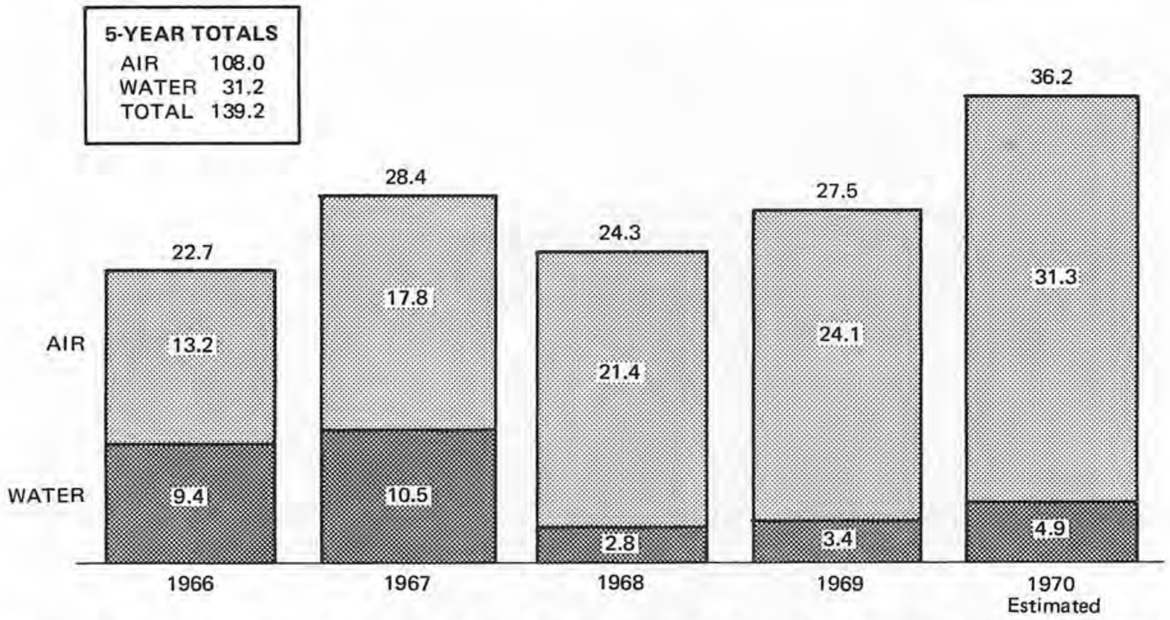
Expenditures on research and development for air pollution control have been for improvement of product quality (primarily gasoline), the development of better process controls, and research into the causes and effects of emissions from use of petroleum products in both mobile and fixed sources of emissions.

Capital investment in various refineries supplying heavy fuel oil in order to reduce sulfur content, previously discussed, is running into the hundreds of millions of dollars and in some cases may equal the cost of the original refinery. With increasing emphasis on land conservation, particularly under the unique conditions found in Alaska, and with steady progress toward further improvement in air and water conservation, expenditures will undoubtedly increase in the future.



CONSERVATION EXPENDITURES - A Survey by the American Petroleum Institute shows that the amount of money which the U.S. petroleum industry is spending in the drive against pollution of air and water has increased 106 percent since 1966. The chart shows that in 1966 total expenditures were $271.4 million, while estimated expenditures for the current year are $559.5 million. Source: API, *Report on Air and Water Conservation Expenditures of the Petroleum Industry of the United States, 1966-1970,* Publication No. 4075 (February 1971).

Figure 3. Air and Water Conservation Expenditures, 1966-1970 (Millions of Dollars).



Research by the U.S. petroleum industry into means for preventing air and water pollution is costing an estimated $36.2 million this year, as compared to $22.7 million in 1966. According to surveys by the API, this year's total breaks down to $31.3 million for research and development costs in connection with air conservation, and $4.9 million for water conservation. The chart, covering the years 1966 through 1970, is based on the API surveys. Source: API, *Report on Air and Water Conservation Expenditures of the Petroleum Industry of the United States, 1966-1970.*

Figure 4. Research and Development Expenditures, 1966-1970 (Millions of Dollars).

The petroleum industry also recognizes that with about 4,000 tankers and 30,000 other large ships plying the world's oceans, some accidents will happen. The industry has therefore taken steps to be sure that means are available to handle the costs of cleanup of oil spills and the costs to persons sustaining pollution damage. For example, voluntary plans have been instituted for handling the costs of cleaning up oil discharges from tankers operating in any part of the world's oceans.

One such plan, the Tanker Owner Voluntary Agreement Concerning Liability for Oil Pollution (TOVALOP), was put into effect in 1969 by seven international oil companies and is available to all tanker owners who wish to become participants. The total tonnage enrolled in the plan now amounts to 96 percent of the Free World's tanker tonnage. TOVALOP provides for reimbursement by participating ship owners to national governments, at the rate of $100 per gross ton on tanker capacity up to $10 million, for expenses reasonably incurred by them to prevent or clean up pollution of coastlines as a result of the negligent discharge of oil from a participating tanker.

In summary, TOVALOP does the following:

- Encourages immediate remedial action by participating tanker owners in the event of a discharge of oil
- Assures financial capability of participating tanker owners to fulfill their obligations under TOVALOP through insurance coverage
- Avoids jurisdictional problems under existing maritime law and practice
- Places on tanker owners the burden of disproving negligence
- Provides a national government with machinery for making valid claims notwithstanding the fact that such government might not, under international or local law, have a legal obligation to remove oil discharged from a tanker or a legal right to recover removal expenses.

Effective April 1, 1971, a new plan provides extended coverage up to $30 million per incident in protection. Administered under the new Oil Companies Institute for Marine Pollution Compensation Limited, it incorporates 38 major oil companies shipping over 80 percent of the crude and fuel oil shipped throughout the Free World.

In fulfillment of the original 5-year term of the plan, TOVALOP will continue for at least another 3 years.

d) Meeting Environmental Costs

The costs of environmental conservation and pollution control are real costs and, in the long run, will finally have to be borne in one way or another by the individual members of society. In general, there are four methods by which these costs can be distributed, either singly or in combination:

- Classifying environmental expenses as a normal cost of doing business
- Granting tax incentives
- Charging economic penalties against societal costs of pollution
- Government subsidies financed from increased taxation (or by reduced government spending in other areas).

Much thought and study have gone into considerations of how best to handle the costs of environmental conservation and many different conclusions have been reached. Most studies have concentrated on how best to equitably distribute conservation and environmental control costs while maintaining minimum inflationary effects and without interfering with normal market mechanisms.

Many economists and conservationists feel that there is little direct incentive in our competitive system for a manufacturer to invest substantial sums of money in pollution-abatement facilities and equipment. The claim is that unless his competitors do the same, he will be unable to recover the extra costs by increasing the price of his product and that, therefore, absent some compulsion or economic encouragements, he will avoid the expense, preventing severe impairment of his ability to compete.

The financial requirements for abating pollution and sustaining an adequate environment are so great that they will probably not be met by any single technique for cost-sharing. Rather, a combination of techniques of societal sharing of costs will, in all likelihood, have to be employed to accomplish the task. There follows hereafter a discussion of each of the several mechanisms of societal cost-sharing which will undoubtedly be considered in some form of combination.

e) Cost of Doing Business

1) Market Incentives

In support of classifying environmental expenses as a normal cost of doing business, a recent report by the Economic Environmental Policy Advisory Committee of the Department of Commerce, entitled "Economic Policy Issues and Environmental Deterioration," stresses the need to achieve a solution to the environmental problem by way of the lowest net cost. The committee concluded that the objective should be to balance abatement costs against the costs of uncontrolled pollution in order to maximize the net benefits to society--to achieve a balance between costs and benefits. In assessing the desirability of minimum tampering with the competitive market mechanism, the committee said that:

> Pollution abatement costs cannot be held to the lowest practical level if they are assigned to the private sector as costs that must be met in the production, distribution and consumption of goods. This means that the costs of pollution abatement, as other costs of production, must find their way through the market mechanism into the prices of goods and services. To this end, the public sector should keep to a minimum any actions which would impede the working of the price mechanism in the competitive market system. Further, those responsible for pollution should be free to decide whether to meet standards through modifications in plant, equipment, process or product or through changes in the methods of handling pollutant by-products. An obvious example would be a power generating plant's decision to burn low-sulfur fuels or desulfurize stack gases.[33]

It is imperative that the choices occasioned by expenditures for pollution control be made explicit. The ultimate costs of consumer products and the relationship between competing sources of energy will be determined, in part, by these environmental control expenditures as they are reflected in costs. Government actions, whether in the form of tax incentives, subsidies or regulatory requirements, will influence decisions of society to a significant degree. The economic bases for the decisions of both the government and society as a whole should be made known to the general public, so that the decisions reached are based on the best available information.

2) Tax Incentives

The Commerce Department Advisory Committee, however, recognized that the normal working of the competitive market system may not be adequate to cope with the occasional crises or emergency situations which would inevitably arise.

The Committee also recognized that government action would be justified to cover transitional periods during which effective pollution control measures are being introduced, to prevent costly short-term trade-offs such as excessive unemployment or disproportionate burdens on certain industries or companies. The Committee cautioned, however, that such assistance as public subsidies or special tax relief should be limited to a specific period of time and provide the means of moving toward the lowest-cost intermediate and long-term solutions that would allow for longer-term technical progress with costs borne by the private producer/consumer sector.

The federal investment tax credit was designed to encourage spending capital funds on pollution abatement.[34] This type of incentive had such support that when the tax credit was suspended from October 1966 to March 1967, air and water pollution control facilities were specifically exempted from the suspension and continued to qualify for the credit, provided they were in conformity with applicable state and federal pollution abatement requirements and policies.[35] And although the new Tax Reform Act of 1969 repealed the investment tax credit provisions, a new provision was adopted for investments in air and water pollution control facilities.[36] The cost of such facilities may be written off over a period of 5 years, provided that the equipment is certified by the state and federal agencies having jurisdiction.

If effective use is made of tax incentives, certain improvements appear to be required:

- Broader definitions of pollution control for tax-incentive purposes
- Simplification of procedures
- More absolute incentives, particularly with the aim of bringing cash benefits closer to the time that investment is made.

Illustrating these points, in the Tax Reform Act of 1969, Congress not only required certification at the state and federal levels, but limited the benefit to additions to facilities in existence on December 31, 1968; required an abatement of an existing condition; further restricted the term "abatement"; etc. Furthermore, the law has been placed in the posture of giving and taking away. If the taxpayer should qualify in investment for the 5-year amortization, the amortization in excess of regular accelerated depreciation becomes a tax preference item, which is subject to the 10-percent minimum tax.

If tax incentives in the area of pollution control are to be used effectively, the scope of the federal laws must be substantially broadened. All facilities which are installed for the purpose of reducing, eliminating, preventing or abating pollution at the producing, processing, manufacturing, storage or distribution site or upon use by the consumer should qualify as pollution control facilities.

If tax incentives are to be provided, they should be well-defined and practicable at all government levels. It is recognized that there are several means by which tax incentives can be provided in the federal tax law. Among these are accelerated depreciation rates, expensing of acquisition costs, and investment tax credits.

Depreciation. Depreciation rates have frequently been used as a tool to achieve economic goals. However, the use of 5-year amortization as an incentive is not the best way to ease private industry's cost burden for pollution control facilities. This incentive is spread over 5 years but the excess of amortization over regular accelerated depreciation is subject to the 10-percent minimum tax penalty. A meaningful tax incentive should have the effect of reducing acquisition costs in the year of purchase.

The goal should be to provide the benefit in or as close as possible to the year of acquisition. Thus, a disadvantage of using depreciation is that its impact is spread out over a number of years. Furthermore, such incentives require additional, costly accounting procedures.

Expensing. A few states (California, for example) now allow a taxpayer to write off the acquisition cost of a pollution control facility as a deductible expense in the year of acquisition or certification. This method gives the taxpayer his tax benefit promptly, and accounting procedures are less burdensome.

Investment Tax Credit. The investment tax credit works as a credit against the income tax liability of the taxpayer. It reduces the taxes that must be paid on a dollar-for-dollar basis. As indicated above, the tax laws have provided a 7-percent investment tax credit for pollution control facilities. This 7-percent rate was also used for all other types of business investments in tangible personal property. Investment tax credits have the following characteristics:

- They are simple administratively from both a government and industry standpoint

- They reduce the cash outflow at the time an investment is made.

New and used facilities acquired through purchase from third parties should qualify. There should be carry-forward and carry-back provisions for excess credits, and the normal life of the asset should not affect the qualification of the facility. A pollution control facility should be defined as any facility which is installed for the purpose of reducing, eliminating, preventing or abating pollution at the producing, processing, manufacturing, storage or distribution site, or upon use by the consumer. In addition, in view of the substantial maintenance and operating costs associated with pollution control facilities, which generally do not get a return on the investment, it would appear that pollution control facilities should be made depreciable at accelerated rates of depreciation. For maximum effectiveness, no portion of the investment should become subject to the 10-percent minimum tax.

Tax incentives as discussed above have strong opposition in some quarters.

3) State and Local Taxes

The majority of states now provide some form of tax relief for pollution control expenditures. The laws of these states vary, however. Few states have forms of tax relief which apply to all three major categories of tax, i.e., sales, income and property taxes. Other states give a tax relief through only one or two of the taxes. Usually the relief in the sales and property tax areas is an exemption from the tax. For the income tax, the tax relief may be a tax credit, a right to expense, or amortization.

While property tax exemptions and accelerated depreciation for pollution control facilities are generally available,[37] at the state and local levels the value of such incentives is quite limited.[38]

The accounting problems of multi-state corporations alone suggest the need for a uniform system among states. In order for the incentive to be effective, a comprehensive scheme is required. Connecticut, for example, provides a sales-and-use tax exemption, a property tax exemption, and a 5-percent tax credit for income and franchise tax purposes.

Local taxes (income, sales and use, and *ad valorem*) are becoming increasingly significant. Generally, local governments follow the state law as to exemption, etc. Where they do not, however, the local authorities may provide their own incentives for pollution control facilities.

4) Subsidies

As an alternative or supplement to the granting of tax incentives, subsidies for pollution control by such means as grants, low-interest loans or artificially low rates for publicly provided services could be considered. A subsidy program, because of the variety of measures available and because it would tackle the problem on a case-to-case basis, would be flexible but very difficult to administer.

5) Government-Imposed Economic Penalties

"The principal obstacle to even greater pollution control expenditures by industry is the generation of enough cash to pay for these nonproductive facilities. Taking money away from industrial companies in the name of a tax on pollution would not help; in fact, it would harm the cause of pollution control."[39]

Section 3.
COOPERATION FOR EFFECTIVENESS

To attain environmental conservation on the most effective and economical basis, cooperation among government, industry and private-citizen groups, as is sanctioned by applicable law, must be continued and expanded. In addition, such coordination of effort among industry sectors should be extended where their operations involve interfaces with one another. This coordination could extend, for example, to planned joint-research programs, exchanges of research results, and joint testing of pollution control equipment and material.

Where a cooperative approach to the solution of an environmental problem would serve the public interest, the Executive Branch should clarify the extent of cooperation that is consistent with the intent of present antitrust laws and, if necessary, seek enactment of such further legislation as would be advisable to authorize the most effective means of dealing with such problems.

Our antitrust laws play a strong role in maintaining competition and diversity of effort that are most likely to produce the lowest cost solution to meeting environmental standards. They properly prohibit collusive action or conspiracy by competitors in matters affecting commerce and public economic interests. However, to achieve the goal of improving the environment, in a few situations it may be that the best interests of society would be served if competitors or complementary industries were permitted to exchange information on a voluntary basis or jointly take actions regarding the modification of products or procedures.

In view of past experience in other areas, it is essential that there be clear legislative sanction where expanded cooperative efforts would serve the public interest in matters of environmental conservation. Should the Executive Branch conclude that, with appropriate and careful governmental monitoring, existing law permits a cooperative approach by industry to environmental conservation, it should define and announce procedures to initiate the desired cooperation. On the other hand, should the Executive Branch conclude that existing law raises a serious question concerning the legality of such an approach, it should propose appropriate legislation to Congress.

A. General Measures

Cooperation can provide many mutual benefits to the affected segments of society. One of the most fundamentally useful forms of cooperation is the rather basic one of continual and open dialogue between industry and government so that government may have at hand the facts regarding the effects of possible decisions before their implementation. This knowledge is of vital importance in assessing the practical limits of technology and economics. For example, where environmental quality does not meet prescribed standards, the constantly moving limits of technology and economics should be taken into account in setting realistic and stable timetables for achievement of the desired quality. Similarly, it is of importance that appropriate segments of industry be made aware of policy planning prior to governmental action.

There is an inevitable period of time involved in planning, financing and implementing measures, and, in a number of instances, developing the necessary technology to comply with prescribed environmental standards. Thus it is essential that, after standards are determined and the time period fixed for compliance, industry be able to rely upon the resulting schedule and not be subjected to continual and exceedingly costly schedule revisions.

In some instances technological advances may reach such a stage of development that they appear available for application in the very near future. If there is strong reason for confidence that such imminent technological advances will help to achieve pollution control objectives, then such technology should be awaited, provided this is in the general public interest.

As another example, imposition of economic penalties is not an effective means of attaining optimum environmental conservation. In general, societal problems affecting the public welfare should be approached directly by the public and its government and not through indirect avenues such as governmentally imposed economic penalties. The imposition of such economic penalties would provide the option of accepting the penalty and continuing the undesirable conduct without abating pollution. This approach also suffers from the virtual impossibility of selecting an equitable method of assessing charges for the vast number of potential pollutants. For example, in the case of effluents, it would be more reasonable to grant plants temporary variances from pollution control regulations, so long as the public safety is in no way compromised, pending the taking of necessary measures to arrive at the desired standards.

There are also many forms of cooperation to obtain the maximum use from available manpower and facilities, thus reducing societal costs of maintaining the environmental quality.

Industry and municipalities should equitably share, as they do now, both the use and cost of their respective waste-treatment facilities. There are industry-community waste-treatment systems which are owned and operated by the industry, not the community. In these cases the community is charged for its share of the use of the facility. In like manner, where the industry utilizes municipal waste-treatment facilities, it does now and should continue to pay its fair share of the costs connected with such facilities.

The petroleum industry actively supports increased attention to harbor cooperatives, to cleanup of oil spills, and to broader arrangements with concerned local and federal groups for such purposes as providing waste-disposal facilities and minimizing the effects of oil spills in coastal and inland waterways. Likewise, governmental efforts to improve coordination and transportation support services to minimize mishaps and damage from oil spills at sea are steps forward in the cooperation necessary to improve protection of the environment.

Improved weather forecasting, ship lanes and navigational aids would provide additional means of preventing massive spills. Cooperation in the establishment of better controls and international standards are needed in all forms of shipping. Advanced cleanup techniques would improve the means of controlling spills.

The petroleum industry and its individual members have mounted a substantial effort and considerable research to improve ability for the prevention and control of oil spills. This effort is being coordinated closely with related governmental programs.

There is also a basic need for cooperation in developing a common understanding of the realities of environmental quality and ways of safeguarding it. Each member of society has a personal responsibility to contribute to the maintenance of an adequate environmental quality. Thus, people should, through all means of communication, including public education programs, be made aware of all of the causes of pollution and the measures which the individual can take to reduce and control pollution. In reducing pollution and in improving the quality of our environment, the role of education is and will continue to be vital, and should be emphasized. Recognizing this fact, the oil and gas industries are expanding appropriate education programs in order to contribute to a wider understanding of these environmental conservation matters.

These are but a few, though important, samples of the requirement for cooperation and the benefits which result from it. They are treated in more detail, along with other examples, in the chapters which follow.

B. Research

Individual petroleum companies carry on intensive research programs to improve products and operations. The research effort alone of the petroleum companies relating to environmental conservation is estimated to have been about $36 million in 1970--an increase of 32 percent over the 1969 expenditure.

In addition, cooperative research into problems associated with air and water conservation has been conducted and/or financed by the petroleum industry over the years. This has been done both in cooperation with government and wholly within the industry.

Cooperative efforts toward water-pollution abatement can be traced back to 1929, with the formation of the American Petroleum Institute's Committee on Disposal of Refinery Wastes. Pioneering air pollution research was begun by the API in 1953 through a research advisory group to its Smoke and Fumes Committee. This current broad research effort represents an expenditure of about $3.5 million a year in direct support of outside research efforts in addition to individual company expenditures and involves projects in both air and water conservation.

1. Air Pollution

Current research efforts in which the petroleum industry plays a significant part involve a wide range of subjects, including automobile emissions, effects of lead and other additives in motor fuels, medical aspects of lead, reactions of sulfur oxides in the atmosphere and many others. Following are some of the principal areas of research, along with an indication of the progress being made.

Multicompany research programs are proceeding with the aim of developing an internal-combustion engine and fuel combination that will emit virtually no harmful pollutants. One, begun in 1967, is made up of six companies from the petroleum industry and five automobile companies (including both U.S. and foreign companies). Another, also started in 1967, includes a petroleum company and an automobile manufacturer.

Objectives of the larger group are to achieve automotive emission levels no higher than 65 parts per million (ppm) of hydrocarbons, 0.3 percent carbon monoxide, and 175 ppm of nitrogen oxides. In several instances, research efforts have accumulated new basic knowledge about the combustion process, the chemical nature of catalytic reactions, the effects of introduced air on hydrocarbon and carbon monoxide control, and the chemical interaction of hydrocarbons and nitrogen oxides in exhaust gases. This program is now moving out of the research phase into development and lab testing of hardware, and in some instances to road testing of vehicles equipped with the new hardware.

Similarly, the two-company program encompasses some basic research on engine combustion. It is also investigating some engine modifications to improve combustion. Fuel evaporation control systems, balanced fuels to minimize engine deposits, specially modified lubricants, recirculation of exhaust gases to decrease nitrogen oxides, thermal reactors for additional combustion, catalytic reactors to render exhaust gases innocuous, analytical techniques for extremely low emission levels, and aspects of atmospheric chemistry and the effects of at atmospheric pollution are in the development stage.

A single company developed a manifold reactor that maintains high exhaust-system temperatures, reducing total emissions of hydrocarbons and carbon monoxide by 80 percent. A multicompany program then developed a synchronized air-injection system for further reduction of hydrocarbons and carbon monoxide emissions, and catalytic reactors for the exhaust system that drastically reduce emissions of both hydrocarbons and nitrogen oxides.

Another accomplishment of the cooperative emission research programs has been the development of effective systems of reducing the evaporation of hydrocarbons. Crankcase storage has been developed as a means of controlling hydrocarbon evaporative emissions. A collection and disposal system utilizes a canister of activated charcoal that soaks up evaporating hydrocarbons from the carburetor and fuel tank and releases them through special valves under controlled conditions to be burned in the engine. This method virtually eliminates evaporative losses, and has been shown to be dependable and durable. Evaporation-loss control equipment is required nationwide on all cars beginning with the 1971 model year.

A related program of somewhat broader scope is being conducted by CRC, a joint industry-government group supported by the Automobile Manufacturers Association, API and EPA. It is perhaps the outstanding example in the conservation field of a joint research effort of industry and government. The program of CRC, at a cost of over $12 million in its first 3 years of existence, is directed by a group of technical and medical experts from the oil and automotive industries and the Air Programs office of EPA. Research work is conducted at universities, government laboratories and private research organizations. The objective of the program is to bring to bear the expertise of the petroleum and automotive industries and the Federal Government on problems created by automotive air pollution. This is done through atmospheric, engineering and medical studies.

Its projects involve such engineering aspects of vehicle air pollution as gasoline additives; use of unleaded fuels; fuel volatility; driver habits and traffic patterns; automobile engine time-temperature surveys; diesel exhaust odors; exhaust gas oxygenate content; exhaust gas particulate matter and polynuclear aromatic content; and inspection, maintenance and surveillance techniques for minimizing exhaust emissions.

Studies of atmospheric chemistry and the medical aspects of air pollution are also being carried on under the CRC program. Already concluded is a survey of current knowledge of the effects of low levels of carbon monoxide on human performance. Other studies have been undertaken on effects of both carbon monoxide and aromatics. Final reports on most of these projects are expected by the end of 1972.

The American Petroleum Institute since 1966 has sponsored extensive industry research into the engineering, scientific and environmental health aspects of the sulfur content of heavy fuels used by industry. This has included a study of the possible chronic or acute health aspects of sulfur oxides and particulates in ambient air, an evaluation of the state of the art and cost of removing sulfur oxides from stack gases, a cost study of methods to reduce sulfur content of heavy fuels, and a wide range of studies into amounts and effects of atmospheric lead. Some projects included in the API's 1970 program are an effort to establish a maximum safe concentration-time exposure level for sulfur dioxide in the atmosphere, a determination of the effect of mixing flue gas with combustion air when using residual fuels, and a study of the cause of lead poisoning in certain domestic animals in Iowa.

2. Water Pollution

In addition to widespread in-house research by individual oil companies in water pollution control, the American Petroleum Institute and the EPA have been working as a government-industry team on research studies in biological treatment processes. These studies have been generally aimed at determining how various hydrocarbon compounds affect municipal and industrial waste-treatment systems and how biological oxidation systems tolerate the presence of oil.

Present studies are examining the effect of low concentrations of oil on continuous systems and attempting to determine the feasibility of pretreating oil before it enters a biological system. Research still to be done includes the effect on biological systems of oil compounds (such as crankcase oil, crude oil, vegetable oil, etc.) and the monitoring of degradation of compounds in such systems.

Since February 1969, an API group has been charged with developing an action program on oil-spills cleanup for the petroleum industry. Its task force on equipment and materials has as its objective the development of an effective total system for containing, recovering and storing oil spilled in the open sea or other rough water. While in-house research has produced skimmers and other equipment operable in fairly quiet waters, the need now is for highly flexible equipment that will be effective in high seas.

This task force has also investigated agents for treating oil spills--sorbent materials, sinking agents, burning aids, dispersants and biological agents. It is compiling in a single volume all pertinent data on available treating agents and is developing standard testing procedures.

A task force on liability and indemnification hopes to develop an insurance plan for oil spills from such sources as offshore drilling platforms, refineries, pipelines or terminals in much the same way that TOVALOP now covers tanker spills.

A task force on response plans has as its top-priority objective the development of an industry response plan for massive oil spills at sea. The group has completed one major project, preparing a model contingency plan for use by individual oil companies. It has now completed an inventory of oil industry installations on or near bodies of water to determine the status of preparedness to deal with oil spills.

A fourth task force is concerned with government liaison, which works with the EPA, Coast Guard and other U.S. agencies, along with the Institute of Petroleum in Great Britain and individual oil companies here and abroad.

3. A Basis for Criteria and Standards

Much has been accomplished both by the separate research efforts of companies, institutions and agencies of government and by the cooperative efforts within and between these groups.

Most of the information and understanding needed to set ultimate objectives, criteria and standards necessary to solve all of our pollution problems is not available. Consequently, the attention of society can well be turned to the support of broad programs of basic research to evaluate more conclusively the effects of contaminants on human health and on the general ecology over the short and long terms. The scope of such an effort is indeed so broad and must be so continual that it will require the full cooperative resources and talents of the business community, governments at all levels and educational institutions.

Industrial research into the ways and means of controlling pollution has laid the foundation for past significant progress and can continue to do so in the future. Federal research expenditures, on the other hand, should neither discourage or encroach on such private research nor interfere with market competition between the various forms of energy. Governmental financing is appropriate for fundamental research studies, such as those designed to advance the frontiers of knowledge pertaining to the quality of the environment and to survey potential resources.

C. Efforts for Understanding

Individual companies of the petroleum industry have recognized the need for more precise understanding of the nature of pollution and means to its control. Separately and cooperatively, they have developed and published substantial amounts of related technical information. This information has been used by them in the training of their own personnel, and by other industries, government bodies and the general public.

Under grants from the American Petroleum Institute, a series of authoritative monographs on the relation of a number of major and minor pollutants to ambient air quality were prepared by established experts in the field of environmental science. These monographs cover various aspects of particulates, oxidants, photochemical smog, sulfur dioxide, carbon monoxide, lead, barium, nickel, manganese, cadmium, zinc and mercury.

As another example, over the years the API Committee on Disposal of Refinery Wastes has played an important educational role, issuing the first volume of its *Manual on the Disposal of Refinery Wastes* in 1935. This manual has been continuously revised and expanded, and presently is comprised of five volumes reflecting in detail the state of conservation technology in oil refining, as follows:

Volume on Liquid Wastes, 1969 (supersedes Vol. I)
Vol. II, Waste Gases and Particulate Matter, Fifth Edition, 1957
(Vol. III was superseded by Volume on Liquid Wastes, 1969)
Vol. IV, Sampling and Analysis of Waste Water
Vol. V, Sampling and Analysis of Waste Gases and Particulate Matter
Vol. VI, Solid Wastes, 1963

Besides these efforts at technical education, both the API and many individual companies have been active in the education of the general public to the problems and possibilities of air and water conservation in the petroleum industry. A series of booklets, films and illustrated speeches has been produced by the API, while most major companies have produced brochures and other materials to explain to visitors and customers what they are doing in the interests of cleaner air and water.

The National Petroleum Council has developed this report in considerable detail in the hope that it can serve both to provide its readers--in government or in the private sector--with a better understanding of the complexities of the problems of pollution control relevant to the oil and gas industries and to provide useful guidelines to their solution. Much indeed has been accomplished by research efforts. Yet most of the information and understanding needed to set ultimate objectives, criteria and standards necessary to solve all of our pollution problems is not available. Consequently, the cooperative resources of society can well be turned to substantial and continuous support of broad programs of basic research to evaluate more conclusively the effects of contaminants on human health and on the general ecology over the short and long terms.

Chapter Two

LAW AND REGULATORY POLICY

Society--including industry, the general public and governments, domestic and international--now has a greater awareness that actions taken to raise living standards must be carried out not only to meet adequately the needs of an expanding population, but also to maintain the quality of the environment as well.

The petroleum industry shares with all other elements of society, including government, the responsibility of assuring that our environment be improved where necessary and that in all cases its quality be adequately maintained for this and future generations. As part of the vanguard of the conservation movement, the petroleum industry has been improving the technology and techniques of petroleum operations in order to achieve maximum recovery of natural resources with minimum waste. It is expanding its efforts to carry out its operations in a manner fully consistent with the needs of society.

However, no single company or industry can solve the problems of environmental conservation in a vacuum. Just as environmental conservation is a problem of all of the elements of society--industry, the general public and governments--so must all of these elements take a constructive part in a societal effort to attain optimum solutions.

All elements of the social order share in the responsibility to control the quality of air, water and land and, at the same time, to exercise this control in a manner which will provide society with other fundamental needs.

Perhaps the first shared responsibility is the orderly development of understanding and good relations. Solving problems of environmental quality is a matter of mutual benefit to industry, government and the general public, with each having skills and resources which can supplement those of the others.

A good working arrangement with government can be achieved where there is a continual interplay of ideas aimed at developing intelligent, well-thought-out laws and regulations. Industry needs to know what government wants, and what government is about to ask it to do; government needs to know what industry can do, what it is trying to do, and how much time and money it is going to take. Best results can often be achieved where industry is asked to participate, in an advisory capacity, beginning at an early stage in the development of policy, laws and regulations.

Naturally, communication to assure orderly development and to enhance the implementation of government regulations is best carried out in an atmosphere of mutual trust and frank and open discussion. Sometimes it is necessary to divulge confidential information, but more often effective communications consist simply of an exchange of general knowledge, leading to better understanding and more intelligent action.

Central topics in any industry/government discussions of the elimination of current problems are time and economics. The government may have public pressure demanding action, while the industry may have knowledge that the necessary technology cannot be acquired for some years. Industry participation can help to assure that adequate consideration is given, in the formative stages of proposed legislation, to the time required for implementation and the economic feasibility of the proposal.

Government and industry share a responsibility to the public to cooperate in the use of all knowledge and skills in the creation of a healthier environment. A good working relationship between government and industry is the strongest basis for an effective solution to these problems.

Section 1
FEDERAL LAWS AND REGULATORY POLICY

The legal aspects of pollution control cover a broad spectrum ranging from international treaties and conventions at one end to local ordinances and regulations at the other. In between are the federal laws on the subject and those at the state level. This portion of the discussion will be addressed to the federal enactments and the programs and policies developed thereunder--specifically, (1) the Water Pollution Control Act Amendments of 1956,[40] as amended by the Water Quality Act of 1965,[41] by the Clean Water Restoration Act of 1966, and by the Water Quality Improvement Act of 1970;[42] (2) the Clean Air Act of 1963,[43] as amended by the Air Quality Act of 1967,[44] and further by the Clean Air Amendments of 1970; and (3) the Solid Waste Disposal Act of 1965.[45]

No discussion of legislation in as dynamic a field as environmental conservation can ever be fully up-to-date. A daily reading of the *Congressional Record* or the *Federal Register* reveals the ever-growing extent of the discussion at the federal level. At the state level the extent of such discussion is multiplied by a factor of 50.

As indicated previously, the NPC Committee on Environmental Conservation chose, as a closing date for this study, the conclusion of the second session of the 91st Congress.

A. Definitions

The federal water and air laws contain no definition of pollution. This omission was probably intentional because of the basic federal philosophy of leaving to the states the primary responsibility of preventing and controlling pollution, including the limits to the concept of pollution itself.

There is, however, a federally recommended definition of water pollution which appeared in the Federal Water Pollution Control Administration's (now EPA's) *Suggested State Water Pollution Control Act*. In this Act, which has been adopted in whole or in part by a majority of the states, pollution is defined as follows:

> (a) "Pollution" means such contamination, or other alteration of the physical, chemical or biological properties, of any waters of the State, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the State as will or is likely to create a nuisance or render such waters harmful, detrimental or injurious to public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or to livestock, wild animals, birds, fish or other aquatic life.[46]

The Council of State Governments in its *Suggested State Air Pollution Control Act* uses these definitions:

> As used in this Act: (a) "Air contaminant" means dust, fumes, mist, smoke, other particulate matter, vapor, gas odorous substances, or any combination thereof. (b) "Air pollution" means the presence in the outdoor atmosphere of one or more air contaminants in such quantities and duration as is or tends to be injurious to human health or welfare, animal or plant life, or property, or would unreasonably interfere with the enjoyment of life or property.[47]

The words "health" and "welfare" appear in both of these suggested state laws and also in those portions of the federal water and air enactments authorizing abatement proceedings with respect to pollution "which endangers the health or welfare of any persons."[48]

Although neither of these words is defined in any of these acts, the Federal Government took the position that the endangerment of health or welfare does not require evidence of the existence of actual harm or injury. "The true inquiry," it is said, "in the light of the policy of the statute, is whether there is a reasonable apprehension of such danger. If this exists, the requirement is met."[49]

It was also the Government's expressed view that the health endangered, being the health "of any persons," refers to the actual state of health enjoyed by persons before pollution affects them. This means, according to this position, that "a preexisting disease or infirmity which renders a person particularly susceptible to injury does not confer immunity upon the source of the injury. A polluter must take his population as he finds it."[50]

In instituting abatement proceedings, the Government has applied a definition of health adopted by the World Health Organization (WHO). "Health," according to this standard, "is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity."[51]

B. Water Pollution

Until 1948 the role of the Federal Government with respect to the quality of our Nation's water resources was very limited. Problems in that area were left largely to the individual states.

1. Navigable Waters

There were some areas of overriding national importance which led the Federal Government to legislate concerning navigable waters as far back as 1890 when the forerunner[52] of the Rivers and Harbors Act of 1899[53] was enacted.

Although the Rivers and Harbors Act was aimed at impediments to navigation, its confusing arrangement has produced results having no relationship to navigation. It contains two basic prohibitions separated by a semicolon. The first makes unlawful the discharge of any refuse matter other than liquid sewage into navigable waters. The second outlaws depositing any material on the banks of navigable waters where it may be washed into such waters. The phrase "whereby navigation may be impeded" follows these two prohibitions, but because a semicolon separates them, the courts have held that each stands alone and that, therefore, the navigation impediment language modifies only the second prohibition.[54]

Thus, refuse dumping is unlawful regardless of its effect on navigation. And refuse has been held to include particles of industrial solid wastes suspended in water and materials of commercial value not commonly thought of as discards or waste, such as aviation gasoline accidentally discharged into a navigable river.[55] These cases also establish the principle that equitable relief could be obtained for the violation of a statute criminal in nature. This was a novel principle of law not previously accepted by courts of equity.

Holdings such as these may be of narrow interest, but the philosophy expressed by Supreme Court Justice William O. Douglas in the majority opinion in the aviation gasoline case has broad implications for those who may seek to give water quality legislation a limited or even a literal construction. His words are worth noting:

> This case comes to us at a time in the Nation's history when there is greater concern than ever over pollution--one of the main threats to our free-flowing rivers and to our lakes as well. The crisis that we face in this respect would not, of course, warrant us in manufacturing offenses where Congress has not acted nor in stretching statutory language in a criminal field to meet strange conditions. But whatever may be said of the rule of strict construction it cannot provide a substitute for common sense, precedent, and legislative history.[56]

Violation of the antidumping provisions of the Rivers and Harbors Act is a criminal offense,[57] and freedom from fault or negligence and absence of knowledge appears to be no defense.[58]

2. Interstate or Navigable Waters

In 1948 a more comprehensive federal approach to the problems of water quality was initiated by the enactment of the Water Pollution Control Act of 1948.[59] Except, however, for limited federal enforcement authority with respect to pollution of interstate waters, the emphasis of this statute was on research, cooperative federal/state development programs and financial aid.

Finally, in 1956 the Federal Water Pollution Control Act was passed,[60] which with its subsequent amendments[61] is the basic federal framework for water pollution control today.

This blanket intrusion by the Federal Government into water pollution was prompted by the belief that the states were not coping with and, because of their limited financial resources, could not cope with the problem. In addition, because so many of the affected waterways were interstate or navigable,* some form of federal intervention seemed appropriate and necessary.

In putting together the federal legislative package, three fundamental questions were faced. A basic one was whether water quality standards should be adopted by the Federal Government or the states. The original proposal introduced by Senator Edmund S. Muskie in 1963 provided for the promulgation of federal standards.[62] Ultimately this issue was resolved by giving the states the initial opportunity to establish water quality standards, with authority in the Federal Government to act only if the states failed to do so in a manner acceptable to the Administrator of the Environmental Protection Agency.

A second fundamental question concerned the type of standards to be established. Should they relate to the quality of the receiving water or to the quality of the effluent discharged, or both? Senator Muskie's original bill provided for standards applicable both to the quality of the receiving water and to the quality of the effluent.† As finally enacted in 1965, the Act omitted any reference to effluent standards and provided only that water quality standards adopted by each state were to be "applicable to interstate waters or portions thereof within such State."‡

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*The federal legislation on this subject applies, by its terms, to "interstate waters" for purposes of quality standards (§ 10(c)(1)) and to "interstate or navigable waters" for abatement purposes (§ 10(a)). From a legal jurisdiction viewpoint, using "interstate waters" as a basis for federal intervention has no constitutional support. The fact that waters cross state lines creates no basis for federal jurisdiction under the commerce clause of the U.S. Constitution. An interstate waterway is not, in and of itself, interstate commerce. It may be a highway or an artery for such commerce. Because the commerce power is all-embrasing, including not only those things directly in commerce but also those that affect commerce, a waterway, even though wholly intrastate, is nevertheless subject to federal jurisdiction if it is a link in an interstate route. (*See* United States v. Appalachian Electric Power Co., 107 F. 2d 769 [4th Cir. 1939], *rev'd. on other grounds,* 311 U.S. 377 [1940].) The Supreme Court has consistently broadened the definition of navigability of waters to the extent that practically no distinction can now be made that implies a limit on federal jurisdiction. (Federal Power Commission v. Union Electric Co., 381 U.S. 90 [1965].) Thus the critical question is whether the activity is within interstate commerce, regardless of navigability.

†88th Cong., S.649 § 4 provided for "...(a) standards of quality to be applicable to such interstate or navigable waters, and (b) the type, volume, or strength of matter permitted to be discharged...."

‡33 U.S.C. § 466 g(c)(1). Proposed legislation pending at the time of this report would impose effluent requirements on all industrial and municipal sources--91st Cong., S.3471, S.3687.

A third fundamental question concerned the adoption of uniform national standards as opposed to flexible standards geared to local conditions. This issue was related to the one of federal *versus* state standards, and the decision to leave the establishment of standards to the states in the first instance dictated the elimination from the Act of any reference to uniform national controls.

Congress in enacting the federal charter declared that the national policy was "to recognize, preserve, and protect the primary responsibilities and rights of the States in preventing and controlling water pollution."[63] To this end, the federal statute provides for grants to assist states, municipalities and interstate agencies in local water-pollution control activities and for opportunities to the states to establish their own water quality standards, failing which, the Federal Government will do so in the case of interstate waters. In addition, the Federal Government is given authority to prosecute polluters by abatement proceedings. Administration of the Act is presently in the hands of the Office of Water Quality of the EPA.[64]

Controversies arose over the Department of the Interior's requirement of secondary treatment or its equivalent for all water discharges,* and over the announcement by the Department of the Interior early in 1968 of its so-called "non-degradation standard" requiring that waters whose existing quality is better than that called for by established standards must be maintained at that higher quality level.†

The secondary treatment controversy raises the issue of whether controls can, under the law, be placed on the quality of discharges rather than on the quality of the receiving water. Those who oppose the requirement maintain that it is an effluent standard of the type rejected by Congress at an early stage in the history of the water quality legislation in favor of standards which, in the language of the Act, shall be "applicable to interstate waters or portions thereof within such State,"[65] thus in their view referring clearly to the quality of the receiving waters.[66]

Iowa elected to be the "guinea pig" in testing this issue. It did not incorporate any secondary treatment requirements in its standards for those portions of the Mississippi and Missouri Rivers within its jurisdiction on the ground

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*The secondary treatment Guideline (No. 8) is as follows: "No standard will be approved which allows any wastes amenable to treatment or control to be discharged into any interstate water without treatment or control regardless of the water quality criteria and water use or uses adopted. Further, no standard will be approved which does not require all wastes, prior to discharge into any interstate water, to receive the best practicable treatment or control unless it can be demonstrated that a lesser degree of treatment or control will provide for water quality enhancement commensurate with proposed present and future water uses."

†The non-degradation standard requires that the following provision be incorporated in all state standards: "Waters whose existing quality is better than the established standards as of the date on which such standards become effective will be maintained at their existing high quality. These and other waters of a State will not be lowered in quality unless and until it has been affirmatively demonstrated to the State water pollution control agency and the Department of the Interior that such change is justifiable as a result of necessary economic or social development and will not interfere with or become injurious to any assigned uses made of, or presently possible in, such waters. This will require that any industrial, public or private project or development which would constitute a new source of pollution or an increased source of pollution to high quality waters will be required, as part of the initial project design to provide the highest and best degree of waste treatment available under existing technology, and, since these are also Federal standards, these waste treatment requirements will be developed cooperatively."

that such requirements were not necessary in order to maintain proper water quality standards for those rivers. Under this circumstance, the Secretary of the Interior convened a conference proceeding pursuant to the statute[67] following which he promulgated federal standards.[68]

The non-degradation standard raised concern not only that it was at variance with the Act's authorization to the states to take water use and value for various purposes, including industrial, into consideration in establishing standards but also that, if strictly applied, it would preclude the development of remote, untouched areas. The Secretary in promulgating the controversial standard justified it under the provision in the statute that standards must "be such as to....enhance the quality of water."[69]

It may not be possible to reconcile completely the factors of quality enhancement on the one hand and use and value on the other, but the controversy seems to have subsided somewhat. This was a result of the Department's apparent willingness to compromise by deleting from the standard the requirement that any deviations be approved by it as well as by the state agency, thus leaving to the states themselves the determination of applications for exceptions. It remains to be seen what course will be followed by EPA.

3. Territorial Waters and the Contiguous Zone

In addition to this basic legislation on water pollution, we have a special enactment plus an administrative regulation applicable to oil spills into our navigable waters, the outer boundary of which is the 3-mile limit, and into the contiguous zone, which extends from the 3-mile limit to the 12-mile limit.

The forerunner of the present law on this subject was the Oil Pollution Act of 1924,[70] which was an attempt to cope with the problem of oil discharges from vessels into the navigable waters of the United States. The prohibitions of the 1924 Act against such discharges were difficult to police as a practical matter and, from an enforcement point of view, the difficulty was compounded by a 1966 amendment to the Act, which made such oil discharges unlawful only if grossly negligent or willful.[71]

A much more stringent approach to oil spills was taken by Congress when it enacted the Water Quality Improvement Act of 1970, which was signed into law by the President on April 3 of that year.[72] It broadly prohibits the discharge of oil into or upon (1) the navigable waters of the United States, (2) the adjoining shorelines, or (3) the contiguous zone. Sources covered by these prohibitions are (1) vessels other than government vessels; (2) onshore facilities, which would include refineries, terminals, manufacturing plants, motor vehicles and rolling stock; and (3) offshore facilities within the 3-mile limit, which would include drilling rigs, drilling platforms, storage facilities and pipelines.[73] Any such deep-water facilities beyond the 3-mile limit would not be covered by this law.[74] They were exempted because the Secretary of the Interior had already covered spills from offshore wells beyond the 3-mile limit by regulations[75] issued under the Outer Continental Shelf Lands Act.[76]

To avoid the automatic intervention of the Federal Government in cases of minor spills, the Water Quality Improvement Act of 1970 applies only to spills "in harmful quantities" as determined by the President.[77] Such quantities, in the light of particular conditions, are to be spelled out in regulations.[78] The Act directed the issuance of regulations which would specify the quantities, occasions, circumstances and conditions to be utilized in characterizing an oil discharge as harmful and therefore prohibited, and those to be characterized as not harmful and therefore permissible. On September 11, 1970, the Department of the Interior issued regulations which defined "harmful quantities" of oil as discharges of oil which (1) violated applicable water quality standards or (2) created a visible film or sheen upon, or discoloration of, the water. However, industry has contended that under the "sheen" standard virtually any discharge containing oil, no matter how minute in quantity, can be construed as harmful since discharges of water containing insignificant quantities of oil can, under some conditions, cause a sheen, although normally they would not do so. Moreover, even though the "sheen" standard did not seem to be technologically feasible at that time, the regulations became effective immediately.

The Act does not create an affirmative obligation on the part of an oil spiller to clean up his discharge, although under certain circumstances he will be required to pay the bill. The affirmative, positive cleanup thrust of this law is directed to the President, who is authorized (1) to remove or arrange for the removal of spills "unless he determines such removal will be done properly" by the discharger,[79] and (2) to prepare a National Contingency Plan for removal of oil spills by federal officials in coordination with state and local agencies,[80] with a proposed budget up to $35 million to finance the program.[81]

There are, however, some affirmative obligations placed on oil dischargers. One is to give immediate notice to the Federal Government of harmful spills under penalty of a $10,000 fine or a year's imprisonment, or both.[82] Another is to pay a civil penalty up to $10,000 for knowingly discharging oil in harmful quantities.[83] A third is to reimburse the Federal Government for the costs of cleanup unless the discharger can prove that the spill was caused solely by an act of God (which is defined as an act occasioned by an unanticipated grave natural disaster),[84] an act of war, the negligence of the United States, or by the act or omission of a third party whether or not negligent.[85]

Absent such exculpatory circumstances, one who discharges oil in violation of the statute will be liable to the Government for the costs of cleanup, subject to the following limitations: (1) in the case of a vessel, $100 per gross ton or $14 million, whichever is lesser, and (2) in the case of an onshore or offshore facility, $8 million except that, in the case of onshore facilities, lower limits may be established by regulations for small plants with not more than 1,000 barrels of capacity. None of these limitations will apply if the Government "can show that the discharge was the result of willful negligence or willful misconduct within the privity and knowledge of the owner," in which event the owner or operator shall be liable for the full amount of the costs.[86]

If the owner or operator of a vessel or an onshore or offshore facility from which oil is discharged in violation of the statute proves that the discharge was caused (1) solely by the act or omission of a third party or (2) solely by such act or omission in combination with an act of God, act of war or negligence of the Government, such third party shall be liable to the Government, subject to the same defenses, limitations and conditions applicable to the owner or operator.[87]

The statute expressly disclaims any federal intention of preempting the field of oil discharges, thus permitting the states or their political subdivisions to impose "any requirement or liability with respect to the discharge of oil into any waters within such State."[88] It must be assumed, in spite of this broad disclaimer, that Congress did not intend to give the states carte blanche approval to legislate or regulate at the local level in a way that would be inconsistent with the federal program. For example, a state law imposing a direct obligation on the operator of an onshore facility to clean up any oil discharge from such facility, or to pay a fine for failure to do so, may well be impossible to comply with, as a practical matter, if the Federal Government itself assumes the primary cleanup obligation, as it has a right to do under the federal statute. Even where there is no preemption, a state cannot impose on one engaged in interstate commerce an obligation with which it is physically impossible to comply because of inconsistent federal requirements in the same field.[89]

The strong recommendation of the petroleum industry has been adopted that no liability for cleanup costs with respect to vessel discharges can have any practical meaning unless there is an obligation to establish financial responsibility on the part of vessels entering U.S. waters. After April 3, 1971, all such vessels of over 300 gross tons must maintain evidence of financial responsibility of $100 per gross ton or $14 million, whichever is less, in accordance with regulations issued by the Federal Maritime Agency.[90]

The new statute[91] repeals the ineffective Oil Pollution Act of 1924.[92] The old Rivers and Harbors Act of 1899,[93] however, still remains in effect,[94] thus portending what may well be serious and inequitable consequences for oil operators because of the mutually inconsistent provisions of these two laws. For example, an unavoidable discharge of a minor quantity of oil from a refinery into an adjacent navigable waterway which may not violate the new 1970 statute, because the amounts involved are not substantial enough to be harmful, and which may not transgress federally approved state water quality standards, may still be attacked under the 1899 Act and the discharger subjected to a criminal penalty up to $2,500.

On December 23, 1970, the President issued Executive Order 11574 requiring the implementation of a permit program under the Act of 1899 "to regulate the discharge of pollutants and other refuse matter into the navigable waters of the United States or their tributaries and the placing of such matter upon their banks."[95] The Secretary of the Army (acting through the Corps of Engineers) has subsequently issued implementing rules and regulations.[96]

In addition to the statutory provisions on oil spills, the Department of the Interior has issued specific regulations covering operations on the Outer Continental Shelf (OCS) under oil and gas leases.[97] The regulations apply only to federal leases on sub-surface lands outside the 3-mile limit. The issuance of these regulations in 1969 followed the Santa Barbara oil leak, and because of this administrative rule-making, Congress omitted from its 1970 oil-spill enactment any provisions on that subject with respect to drilling operations on the OCS.

Although the Secretary of the Interior stated that it was his intention to impose unlimited and absolute liability on companies holding Outer Shelf leases for cleaning up oil spills regardless of fault or negligence,[98] there is some question whether the language of the regulation goes that far. The language provides:

> If the waters of the sea are polluted by the drilling or production operations conducted by or on behalf of the lessee, and such pollution damages or threatens to damage aquatic life, wildlife, or public or private property, the control and total removal of the pollutant, wheresoever found, proximately resulting therefrom shall be at the expense of the lessee.[99]

The words "proximately resulting therefrom," i.e., from the drilling or production operations, are legal words of art connoting the absence of some outside controlling force such as an act of God, act of war or act of a third party. If a vessel operated by someone else runs into an offshore drilling rig causing the well to discharge oil into the surrounding sea without any contributing fault or negligence on the part of the well operator, the pollution damage is not the proximate result of the drilling operation but of the act of a third party.

Another question with respect to the Secretary's regulations is their application to existing leases. The Outer Continental Shelf Lands Act authorizes the Secretary of the Interior to prescribe regulations for the prevention of waste, the conservation of natural resources and the protection of correlative rights.[100] Pursuant to this authority the Secretary's regulations prior to Santa Barbara provided simply that the lessee shall not pollute the waters of the high seas.[101] The statute authorized a fine of up to $2,000 for a knowing and willful violation without any cleanup provisions or other penalties, except possible forfeiture of the lease.[102] The new regulatory obligations issued in 1969 purport to be binding on lessees under existing leases as well as under new leases. Many lawyers question the legality of the former on the ground that a valid binding contract, such as an oil and gas lease, cannot be unilaterally amended by one party to impose more burdensome obligations on the other than those existing at the time the contract was made. A suit against the Government based on this theory is pending.[103]

The Act does provide that the laws of each adjacent state as of August 7, 1953, shall apply to the Outer Shelf to the extent that they are not inconsistent with federal laws and regulations.[104] Under this provision it may be argued that the imposition of absolute liability, even as to existing leases, is justified if state law as of August 7, 1953, so decreed.[105] But contrariwise, it will be said that any such rule of absolute liability under state law is inconsistent with federal regulations which impose liability only for failure to take "reasonable precautions for keeping all wells under control"[106] and to take "reasonable precautions to prevent any well from blowing open."[107] Furthermore, the standard lease forms applicable to offshore Santa Barbara provided that the lessee was not responsible for casualties occasioned by causes beyond his control.

C. Air Pollution

The Federal Government has moved more slowly on the air pollution front than it has in connection with polluted waters. It was not until 1955--7 years after the Water Pollution Control Act of 1948--that Congress put the Federal Government in the air pollution picture by the passage of the Air Pollution Control Act.[108]

The states'-rights principle was recognized by the provision that "the prevention and control of air pollution at its source is the primary responsibility of states and local governments."[109]

The 1963 Clean Air Act provided, among other things, for the development of air quality criteria by the Federal Government through HEW (now the responsibility of EPA) to guide local control agencies and for abatement proceedings patterned after those in the 1956 Water Pollution Control Act. Added in 1965 was a provision authorizing HEW to establish national standards for emissions from new motor vehicles.[110]

A major weakness, however, in the 1963 Act was the absence of any program for establishing air quality standards other than for automobiles. This ineffectiveness led to the Air Quality Act of 1967, enacted in November of that year.[111]

That law (amended further in 1970) made applicable to air much of the philosophy and procedural arrangements previously written into the water program, including the issuance of criteria by the Federal Government and the provision for states to have the opportunity to adopt their own standards in the light of those criteria.[112] If a state fails to adopt standards or if those adopted are found inadequate by EPA, the latter is authorized to promulgate federal standards for such state.[113]

Also patterned on the Water Act are the abatement provisions of the Air Quality Act. In addition, immediate action for an injunction to stop pollution is authorized when there is an emergency endangering public health.[114]

The core of the 1967 Act is the standard-setting procedure. The provisions follow the pattern of the earlier water pollution law, leaving the initial opportunity and responsibility for establishing ambient air quality standards to the states. One jurisdictional difference, however, is the concept of control regions in the Air Quality Act, some of which will encompass areas in more than one state.

Another dissimilarity in the standard-setting procedures under the water and air statutes results from the legislative history which makes it clear that in the air field the implementation plans to be formulated by each state in support of its ambient air standards should contain emissions controls applicable to the sources or classes of sources of various discharges.[115]

It is possible to justify different approaches to the setting of water and air standards so as to make a valid distinction between receiving water standards only, on the one hand, and both ambient air and emissions standards on the other. Not every drop of water must be fit to drink by human beings. In addition to our potable needs, waters serve a variety of other requirements, including industrial, agricultural and recreational uses. Because of these varying uses (which will differ from stream to stream, depending on primary water needs), a preferable degree of flexibility can be achieved by the use of stream standards alone, which are geared to local requirements, than by effluent standards, which by their very nature are rigid and inflexible and thus not as amenable to adaptation to local conditions.[116]

There is also a practical justification for differing approaches to water and air standards. Rivers, streams and lakes occupy fixed channels or areas. Dischargers on their adjacent shores are therefore more readily identifiable, and their effluents are relatively easy to monitor. Thus it is not an impossible administrative burden to police shoreside operators in an enforcement program aimed at maintaining receiving water standards. Our ambient air on the other hand has no boundaries. Dischargers into that air are everywhere. Each individual exhales carbon dioxide as he breathes. To attempt to control the quality of such an all-pervasive medium, with potential polluters literally scattered all over the map, by ambient air standards alone without emissions controls would probably impose impossible administrative and enforcement burdens.

As justifiable as air emissions controls may be, they should be framed in terms of limitations on types and amounts of discharges from particular sources or classes of sources, as distinguished from requirements specifying kinds or types of emissions control equipment. To tell an emitter what he can discharge into the air may be proper. To tell him how to control his emissions is not. Each source should be free to determine its own method of control. To do otherwise, by making mandatory specified control techniques or equipment, would discourage the development of new technological improvements.

There is nothing inconsistent between this caveat and the Air Quality Act's direction to HEW (now to EPA) to issue information on those recommended pollution control techniques, the application of which is necessary to achieve levels of air quality set forth in the agency's criteria. The purpose of this provision is to disseminate, in the words of the Act, "data...on the latest available technology and economic feasibility of alternative methods of prevention and control of air contamination including cost-effectiveness analyses."[117] The reference in the quoted language to "alternative" techniques makes it clear that the choice among the recommended methods should be left to the individual sources of air contamination.

In the light of all of these comments with respect to ambient air standards, it is obvious that a degree of flexibility was intended by Congress so that regional standards could be adapted to local conditions. This, of course, is borne out by the fact that the bill which became the Air Quality Act of 1967 contained, when it was introduced, authorization to HEW to establish national emissions standards for particular industries. After much testimony in opposition to this provision, it was deleted with, however, a direction to HEW to conduct a 2-year study of the issue with respect to stationary sources.*

The 1965 amendment to the earlier Clean Air Act of 1963 giving HEW the authority to establish national standards applicable to emissions from new motor vehicles was reenacted as Title II of the 1967 Act,[118] but with an express provision making it clear that the Federal Government was preempting the field so that the basic philosophy of leaving standard-setting to the states would not be applicable to new automobiles.[119] This provision settled the arguments that had been raised under the 1965 amendment because of the absence then of any preemptive language. The 1967 recodification makes sense, because the manufacture of moving sources of air pollution, such as motor vehicles, which travel from state to state, cannot adequately be controlled under varying local regu-

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*Pub. L. No. 90-148, § 211(a), 81 Stat. 503. Pending legislation would establish nationwide air quality standards and national emissions standards for stationary sources emitting hazardous pollutants.

lations. The burden on automobile manufacturers of turning out cars meeting individual and differing state standards would be impossible.

In spite of these logical arguments for uniform national emissions standards for new motor vehicles, as opposed to the contrary ones which won the day for stationary sources, an exception was carved out for California.* Because of its longer experience in the southern part of the state with smog problems, particularly from automobile emissions, and because of its earlier laws and regulations applicable to such emissions, it was given an exemption from the preemption provision permitting it to enforce its own stricter standards.

Also part of Title II is a section dealing with registration of fuel additives under which EPA is authorized to require specified reports from fuel and additive manufacturers.[120]

The use of additives in gasoline and other fuels to improve their properties prompted these registration requirements. The purpose of the registrations is to give EPA factual information about the use of additives and their composition, so that the Government can by its own tests determine the air pollution effect of the combustion products of fuel additives.

The 1967 Act was the subject of major revisions and modifications by the Clean Air Amendments of 1970. The bill enacting these amendments was signed by President Richard M. Nixon at the close of the year.

The main thrust of the 1970 law is to increase the power and authority of the Federal Government to cope with air pollution on a national level while at the same time maintaining the basic premise of the earlier underlying legislation that "each State shall have the primary responsibility for assuring air quality within the entire geographic area comprising such State."

The significant provisions are as follows:

- The EPA is to issue criteria for major pollutants from mobile and stationary sources which have an adverse effect on public health and is then to promulgate regulations prescribing a national primary ambient-air-quality standard to protect public health and a national secondary standard to protect public welfare for each pollutant. Each state must promulgate an implementation plan for these federal standards. If a state fails to act, or if its implementation plan is unacceptable, the Administrator of EPA is authorized to promulgate an implementation plan of his own.

- The Administrator is directed to publish a list of categories of stationary sources, and to establish federal standards of performance for new stationary sources.

- He is also to publish a list of hazardous air pollutants (pollutants to which no ambient air quality standard is applicable and which cause an increase in illness and mortality) and to prescribe emissions standards for each hazardous pollutant.

- The Administrator must prescribe standards applicable to the emission of any pollutant from any new motor vehicle or engine which causes pollution or endangers health. The manufacturers of motor vehicles have until January 1, 1975 (for 1975 model cars), to attain a 90-percent reduction in emissions of carbon monoxide and hydrocarbons allowed for 1970 models. During and after the 1976 model year, emissions of oxides of nitrogen from new vehicles or engines must be reduced by 90 percent from the average emissions actually measured dur-

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*Pub. L. No. 90-148, § 208(b), 81 Stat. 501. Pending legislation would establish nationwide air quality standards and national emissions standards for stationary sources emitting hazardous pollutants.

ing the 1971 model year. Auto makers can seek a 1-year extension of these deadlines. For carbon monoxide and hydrocarbons, the earliest date they may apply for such an extension is January 1, 1972, and for oxides of nitrogen, January 1, 1973.

- As in the Air Quality Act of 1967, the Administrator may designate any fuel (including, but not limited to, motor fuels) or fuel additive; after such dates as he may prescribe, it is unlawful to sell, offer for sale, or introduce into commerce such fuel or additive unless the Administrator has registered it. For the purpose of registering a fuel or additive, the fuel manufacturer must supply the commercial identifying name and manufacturer of any additive contained in the fuel, the range of concentration of any additive in the fuel and the purpose-in-use of any such additive. The additive manufacturer must notify the Administrator of the chemical composition of the additive.

Under the 1967 Act, registration was automatic upon compliance with these requirements. Under the new law, however, the Administrator may also require the fuel or additive manufacturer to--

- Conduct tests (in conformity with procedures and protocols established by the Administrator) to determine potential public health effects of such fuel or additive (including, but not limited to, carcinogenic, teratogenic or mutagenic effects), with the results not to be considered confidential

- Furnish the description of any analytical technique that can be used to detect and measure any additive in the fuel

- Specify the recommended range of concentration and purpose-in-use of the additive

- Provide such other information as is reasonable and necessary to determine the emissions resulting from the use of the fuel or additive, its effect on the emissions control performance of any vehicle or engine, and the extent to which the emissions affect the public health or welfare.

The Administrator may control or prohibit manufacture or sale of any motor vehicle fuel or fuel additive if the emissions therefrom will endanger the public health or welfare, or if its combustion products will interfere with the performance of any emissions-control device in general use or sufficiently developed that it could be in general use in a reasonable time if the fuel or additive were regulated. Prior to controlling or prohibiting the manufacture or sale of any fuel or additive, the Administrator is required to "consider" all relevant medical and scientific information available to him, as well as other technologically or economically feasible means of achieving emissions standards.

After the Administrator has taken any action controlling or prohibiting the manufacture or sale of any fuel or fuel additive, no state other than California may prescribe regulations for such fuels or additives unless they are identical to those prescribed by the Federal Government or unless they are approved by the Administrator as being necessary to achieve national air quality standards.

Provision is made under the 1970 law for federal aircraft-emissions standards and for the creation of an Office of Noise Abatement and Control.

The Federal Aviation Act of 1958 is amended by adding a new provision for federal regulation of the composition or chemical or physical properties of any aircraft fuel or fuel additive to control or eliminate emissions which the Administrator (of EPA) determines "endanger the public health or welfare."

Any person may bring a suit against any person, including the United States (where permitted by the Constitution), who is allegedly in violation of an emissions standard or an order issued by the Administrator or a state, except that before commencement of the action the plaintiff must give the alleged violator, the Administrator and the state 60 days' notice, and there must be no abatement action pending as a result of such notice at the time the suit is filed.

D. Land Pollution

1. Disposal of Solid Wastes

Our Nation's primary environmental efforts have so far been directed to effluent discharges directly into our waterways by municipal sewage systems and shore-side manufacturers and to emissions into our ambient air from municipal power plants and private industry. In addition we have a hybrid situation, involving to some degree both water and air pollution problems, but arising from a completely different source--the disposal of solid wastes.

Attempts at the federal level to cope with the problem are expressed in the Solid Waste Disposal Act which was enacted in 1965.[121] This act is limited to authorizations to the Department of the Interior and EPA to undertake research and to make grants to state and local agencies for solid-waste disposal programs.

2. Disposal of Brines

In the early days of the oil and gas industry, disposal of brines was a source of land pollution. More recently, deep-well disposal of brines has been carried out extensively without known pollutional effects. This effort has been conducted under state control, which has been adequate to effectively preserve the environment and, more particularly, underground areas. Such control typically calls for the issuance of a permit to dig disposal wells based on applications showing engineering and geologic feasibility. This effort on the part of the states has been cooperative with the U.S. Geological Survey (USGS), which has lent its expertise to state agencies.

The petroleum industry has been particularly proud of its waste-water disposal program through injection wells which return the brine to the producing formation. The figures themselves on this successful operation are impressive. A recent USGS report states:

> Generally the earliest, and by far the most extensive, disposal of unwanted liquids deep beneath the land surface has been by the petroleum industry, to dispose of the brines that are incidental to the extraction of petroleum. The magnitude of such disposal is impressive--Texas alone has about 20,000 brine-injection wells...and Kansas had issued permits for about 3,000 such wells as of 1960...[and] the volume of brine injected into the ground each year is several billion gallons (on the order of 10,000 acre-feet)....[122]

The return of brine to the producing formation not only serves as an effective method of disposal but also tends to restore the underground equilibrium which existed before it was extracted along with oil and gas.[123]

E. Interstate Compacts

Both the Federal Water Pollution Control Act and the Air Quality Act authorize two or more states to enter into compacts for cooperative pollution control programs.[124] However, these cannot become effective until approved by Congress.[125]

With air and most of our major waterways recognizing no state boundaries, it might be supposed that the invitation to use the compact approach in coping with multistate pollution problems would have been widely accepted. Such has not been the case. There are only a handful of interstate compacts entered into specifically for the purpose of creating regional organizations to control pollution of interstate waters.[126]

There have also been some compacts with broad jurisdiction over planning and developing the utilization of water resources of particular water basins; a few of these have included control over water pollution.[127]

Although there is a 1961 agreement between New York and New Jersey establishing an Interstate Sanitation Commission, it has limited and ineffectual jurisdiction over matters relating to interstate air pollution. There are three proposed compacts specifically covering air pollution which have been pending in Congress since 1967, but none has been approved.[128] This is the extent of multistate air pollution legislation.

This rather surprising lack of enthusiasm for the compact technique has been explained on several grounds. The slow, cumbersome and involved procedure in enacting a compact is in itself a deterrent. The legislatures of all states involved must agree on identical bills, which the governors must accept, followed by similar agreement by the Senate and the House in Washington and by the President. Any deviation along this line from the original formula means that the measure must go back and start all over again.

The interjection of the Federal Government on a broad scale in pollution abatement as a result of the Federal Water Pollution Control Act of 1956 and the Air Quality Act of 1967 has probably removed some of the impetus to solve these problems through interstate agencies. This is particularly true with respect to air pollution because of the provisions of the Air Quality Act of 1967 calling for the designation of air quality control regions, which in many cases encompass multi-state areas. One of the legislative sponsors of the Illinois-Indiana air compact, which is still languishing in Congress, attributes the absence of any large-scale push behind air pollution compacts to this federal intrusion. "Before the 1967 Act, interstate compacts made a lot of sense," the sponsor said. "Now, they're probably not needed."[129]

F. National Environmental Policy

The National Environmental Policy Act of 1969 established for the first time an overall policy of the Federal Government with respect to the environment. Its purposes are: to declare a national policy which will encourage productive and enjoyable harmony between man and his environment to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; to enrich the understanding of the ecological systems and natural resources important to the Nation; and to establish a Council on Environmental Quality.

Title I of the law specifically declares that it is the continuing policy of the Federal Government, in cooperation with state and local governments, and all other concerned public and private organizations to create and maintain conditions under which man and nature can exist in productive harmony and fulfill the social, economic and other requirements of present and future generations of Americans. Further, it prescribes it to be the continuing responsibility of the Federal Government to improve and coordinate federal plans, functions, programs and resources to accomplish the objectives of the national policy, and recognizes that each person should enjoy a healthful environment and has a responsibility to contribute to the preservation and enhancement of the environment.

Specific applications of these general principles are discussed throughout this report.

Section 2.
STATE AND LOCAL LAWS AND REGULATORY POLICY

The purpose of this section is to indicate, to the extent feasible, the general direction and trend of the maze of state and local laws and regulations. To attempt a recitation of state and local laws without imposing any such judgment factor would be like an analysis of a psychedelic painting color by color.

Because the Federal Government has been active in promoting pollution laws in the various states, there has been in the past some degree of uniformity, particularly in the water field. The field, however, is not static. New developments are taking place daily. If there has been some order in the law with discernible trends, the headlong rush to enact new laws and regulations, often with little intelligent consideration, is fast creating an untenable situation.

A. Water Pollution

1. Common Law

The early history of the United States clearly shows little, if any, concern for our natural resources, particularly water. In spite of our attitude, however, there was a body of law in England, which was brought into our common law, known as the doctrine of riparian rights. Although this doctrine has been severely limited by statute in some states, it is still a viable and recognized precept.[130]

Simply stated, "Riparian rights are private real property rights to the beneficial use of water from a natural watercourse or stream contiguous to the land to which the rights attach."[131]

Each riparian owner is entitled to the amount of water reasonably necessary for useful and beneficial purposes. The question is, of course, what is reasonable. Generally, the courts have tended to support uses for domestic purposes, including drinking. Where there is a shortage of water, the upper riparian owner has the right of first use of the water for domestic use. But if the use upstream is for some other purpose, it is unlawful if it prevents domestic use by the downstream holder.[132] In a bucolic society which had a reasonably sufficient supply of water, this doctrine worked.

Another legal doctrine is the one of appropriative rights, which means first in time, first in right. It follows, therefore, under this doctrine that if the first-in-right used water for irrigation, the lower riparian owner could not expect pure water for drinking purposes. Any deterioration of water quality within reasonable limits would not be actionable.[133] Under either of these doctrines, however, gross pollution would be the subject of action.

Generally, the cases which arose under these doctrines concerned themselves with flow and use of water and only secondarily with purity. Therefore, the natural remedy sought would be for an injunction. Harm must be, however, irreparable in order for a court to grant this extraordinary relief. Further, the injury must be one of a continuing nature.

Interwoven with these theories is the old common-law doctrine of nuisance. There are two types of nuisance--private and public. A private nuisance was originally defined as anything done to the hurt or annoyance of the lands, tenements or hereditaments of another. A public nuisance, on the other hand, is one which affects an indefinite number of persons, or all the residents of a particular locality, or all people coming within the extent of its range or operation, although the extent of the annoyance or damage inflicted upon individuals may be unequal.[134]

A practical illustration of the difference is a cow dying from drinking polluted water (private) *versus* a fish kill (public). In either case the courts have insisted that material harm be shown.[135]

Use of the nuisance theory would more easily lend itself to damages. Where there was a continuing nuisance, an injunction could be sought with all of the attendant problems set forth above. However, the cow or the fish killed through the pollution of a stream are more likely candidates for a damage suit.

Various theories of damages have from time to time been set forth. One court held that the measure was the cost of cleaning up the stream limited by the total value of the property from which the pollution emanated.[136] This certainly is not the type of solution that would lend itself to the restoration of polluted streams. It appears that a public-nuisance theory would circumvent this problem but here, as always, the problem is proving that the injury is the result of the defendant's pollution.[137]

All in all, the common law was not a satisfactory vehicle for solving water pollution problems. The result was a turning to legislatures for solutions.

2. Statutory Law

As has been described in Section 1, the federal concept of protecting our waterways is almost a century old, dating back to the 1890 forerunner of the Rivers and Harbors Act.[138] However, as long ago as 1787 New York passed a law authorizing boards of health to monitor the quality of water used for drinking purposes.[139]

The early part of this century witnessed a more deliberate approach to the problem. It was attacked as an antidisease issue. By 1930 most states had responded by vesting regulation in one or more state agencies, usually in a department of health.[140]

The war slowed down the process of regulation and it was not until the late 1940's and early 1950's that the program with which we are familiar today got under way.[141] Several states with acute problems had already undertaken comprehensive programs, such as California in 1949.[142] The earlier programs were under fire from many sources. The chief deficiencies cited were--

- Lack of statutory authority to act
- No forceful administration of existing acts
- Inappropriateness of public health dominion
- Lack of centralized control.[143]

This last criticism has been substantially met with the U.S. Senate Committee on Public Works reporting in 1963 that 35 states had a modern and comprehensive approach to pollution control.[144] In California, however, three independent agencies have jurisdiction over water--the State Water Resources Control Board, the State Department of Public Health and the State Department of Fish and Game.[145]

In many states, the fish and game commissions have a say in water purity along with the departments of health and water. Differing policies may result when control is not centralized. For example, a department of agriculture may be attempting to spread water over the land for irrigation purposes and even subsidizing such moves, while the fish and game commission may be subsidizing retention of water in ponds and lakes. The need for coordination is essential and perhaps even more imperative in light of our present-day needs.

The Federal Government, under the auspices of the U.S. Public Health Service, began moving into the field in 1950 with the publication of the *Suggested State Water Pollution Control Act*.[146] This was adopted by the Council of State Governments in 1951.[147] The suggested act was revised and republished in 1965 by the U.S. Public Health Service. (This activity is now lodged in EPA.)

With all of the effort put forward to unify state laws, there is still much divergence. Two states have nothing more than dumping statutes.* Fourteen states have separate control agencies.† While the majority keep their control within their departments of health, in some the control is administered by separate boards within the departments± and in others by the departments themselves.§

Generally, the functions of the board or commission will fall in one of the following categories: (1) advisory only; (2) making policy decisions but implementation and enforcement lodged in some other agency; (3) making and enforcing policy.[148]

As the powers of the boards or commissions vary, so do their effectiveness. The most effective boards will normally make policy. They are severely hampered, however, where their jurisdiction is shared with other agencies or where they do not have direct access to relevant information and expertise.

In some areas where industry representatives are local board or commission members, questions of conflict of interest have been raised. It should be noted, however, that the interests of society can generally be best served if the responsible boards or commissions have the advantage of knowing the technical and economic feasibility of their policies at the earliest stages of policy development.

Enforcement of state laws and regulations has been left for the most part to persuasion, as evidenced by the paucity of reported cases.[149] Under state procedure, most states can issue cease-and-desist orders, and failure to comply can result in criminal penalties.[150] The states have been reluctant to invoke these penalties. Their reluctance is understandable if one considers the common-law criteria. The burden of proof is strict and what is sought to be accomplished is to identify and punish the polluter causing the problem. This is difficult, if not impossible, when the stream passes a major industrial area--where, of course, the problem is most acute.

With respect to the specific problem of oil pollution, several states (such as Florida, Massachusetts and Maine) recently have enacted legislation which unnecessarily duplicates or creates obligations inconsistent with those obligations created under the federal Water Quality Improvement Act of 1970.

3. Effect of Federal Legislation

The Water Quality Act of 1965,[151] as discussed in Section 1, has had a profound effect on state regulation. As has been previously brought out, although the bill as originally introduced provided for the setting of standards by the Federal Government,[152] this approach was rejected and the states were given an opportunity to set standards acceptable to the Federal Government. If the states failed to act, the Federal Government would set them.[153] The belief was that the states had not lived up to their responsibilities. The states, following the passage of this Act, began to formulate standards in compliance with the Act.

In attempting to enforce their pollution laws against other agencies of the state, such as municipalities, state governments face difficult problems. One state, Minnesota, solved this problem 6 years ago by granting the state agency power to take over the municipal functions if the municipality did not per-

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*Arizona and Nevada.

†Alabama, Connecticut, Illinois, Indiana, Michigan, Minnesota, Montana, North Dakota, Oklahoma, Texas, Vermont, Washington, West Virginia and Wisconsin.

±Arkansas, Colorado, Delaware, Iowa, Kentucky, Maine, Missouri, Nebraska, New Hampshire, New York, North Carolina, South Dakota, Tennessee, Virginia and Utah.

§Alaska, Arizona, Florida, Georgia, Hawaii, Idaho, Kansas, Maryland, Massachusetts, Nevada, New Jersey, New Mexico, Mississippi, Rhode Island and Wyoming.

form.[154] Most states, however, have not faced up to the problem. Debate on this issue rages almost daily in the halls of Congress and in state capitols throughout the country. The problem is primarily one of money.

B. Air Pollution

1. Common Law

The doctrine of nuisance has been previously defined, and it has been shown that application of this doctrine is difficult in the field of water control. It is equally if not more difficult in the field of air pollution, because air knows no boundaries.

As one judge considering the problems of the nuisance doctrine put it:

> In the whole field of law there is nothing more difficult to capture within the confines of a workable definition than the concept of nuisance, nothing more dependent on the peculiar facts of the given case. Like the legendary and elusive gadfly Tyll Eulenspiegel, it scoffs at the conventionalities of the Law.[155]

It would appear, therefore, that a plaintiff could recover in only a very unusual case. Where, however, the offense can be classified as a nuisance *per se*, plaintiffs have been more fortunate. It has been defined as follows:

> A structure, object, occupation, or act that is a nuisance at all times and under any circumstances, regardless of location or surroundings, which cannot be so conducted or maintained as to be lawfully carried on or permitted to exist.[156]

There were early cases that considered the possibility that oil refineries were nuisances *per se*. The general rule evolved that they were not, so long as they were properly operated and maintained. This rule has been altered in some cases where courts have permitted recovery to plaintiffs even without any negligence having been shown.[157] The answer appears to be that each case rests on its own facts.

Many believe that the area of the law controlling air pollution is new and that it is in only very recent years that the courts have even considered the problem, let alone acted on it. This is not true. In 1916, the Supreme Court of the United States in an early smoke case held that municipal ordinances controlling smoke were constitutional even if it meant the closing of a business.[158] The Court considered the problem severe enough to warrant such harsh relief. Later cases reveal some vacillation,[159] but it is interesting to note that the Supreme Court had no difficulty over half a century ago.

More recently an eminent jurist, the late Chief Judge Vanderbilt of New Jersey, commented on smoke ordinances as follows:

> The reason for a municipality making unlawful the emission of smoke is readily apparent. The issuance of dense smoke from a single chimney, in and of itself, may be altogether harmless and cause no inconvenience or damage to the public, but if smoke of like density issued from hundreds of chimneys, the contamination of the atmosphere would be substantial and the injury to the public considerable, yet for lack of the requisite elements of a public nuisance at common law, the municipality could obtain no relief by way of indictment. Ordinances making unlawful the emission of smoke are therefore obviously necessary and reasonable and a valid exercise of the local police power.[160]

In spite of the widespread recognition in the courts of the extent and seriousness of the problem, there is still difficulty encountered in proving damages. This is particularly true where there are many stationary sources in one area.[161] The class action brought against a number of alleged polluters shows signs of increasing popularity. It is still too early to measure the success of this approach and the attendant problems of determining classes under Rule 23 of the Federal Rules of Civil Procedure.

Another interesting development is the enactment in Illinois in 1969 of a law granting the Attorney General authority to bring suit to enjoin both air and water pollution[162] despite abatement programs approved by regulatory agencies. This overriding, direct-action type of attack may make headlines, but it does not foster the government-industry type of cooperative efforts that are necessary if the problems of pollution are to be solved.[163] Similar legislation has now been enacted in Michigan.

While the courts have not had trouble in finding a legal basis for closing down a business, in several recent cases they have been reluctant to do so. The most notable example is the Bishop Processing Company case in Maryland. The courts, after setting many deadlines, finally enforced their orders to close the plant.[164]

In March 1970 the New York Court of Appeals refused to close down a cement plant found to be a nuisance. A digest of the decision describes the Court's action as follows:

> Cement company's plant caused injury to adjoining property through dirt, smoke and vibration. Neighboring land owners sued for an injunction and damages. The condition was found to be a nuisance. Should an injunction be granted? In particular, should the court merely resolve the litigation equitably between the parties, or should it use the case to promote broad public objectives? Held - It is the duty of the court to settle the case before it. Although larger public issues may also be resolved by the case, it is a rare exercise of judicial power to use a decision in private litigation as a purposeful mechanism to achieve direct public objectives greatly beyond the rights and interests before the court. Effective control of air pollution is a problem not to be solved as a by-product of private litigation. The damage to plaintiffs' properties is relatively small in comparison with the value of defendant's operation and the consequences of an injunction. Denial of an injunction is the appropriate remedy even though it requires overruling the longstanding doctrine that an injunction will be granted where a nuisance is found and the complainant shows any substantial damage.[165]

2. Statutory Law

While smoke ordinances have been with us for many years, the advent of comprehensive control statutes and enabling acts on the part of the states is of fairly recent origin. The State of California must be considered the leader in this field, having enacted the earliest, most comprehensive set of controls. The Air Pollution Control District Act, enacted in 1947, was notable for many things, but principally for its regional approach. It was the first time that a state recognized that ambient air is fugitive in the sense that it does not adhere to or respect artificial boundaries.[166]

The pattern of the state statutes is a familiar one. The Council of State Governments promulgated a model state air-pollution-control statute in 1966.[167] This model has been adopted in whole or in part in many states. Typically the state's department of health is the administrative and enforcement agency in charge of pollution abatement. There is usually a board or commission which operates as a regulatory and policy board, but the enforcement remains in the department.

The statutes are for the most part very broad in nature, leaving the passing of regulations to the appropriate administrative agency. This gives the agency broad discretion in implementing the state policy declaration contained in the statute. Since the advent of these statutes and development of the state of the art is so new, most of these states are still in the process of developing regulations; however, by 1967 all but 6 of the 54 U.S. jurisdictions had enacted some form of control legislation.[168]

At the local level, ordinances were enacted against smoke at an early date.[169] More sophisticated ordinances have followed.[170] An outstanding example was the enactment in 1966 of Local Law 14 in New York City. Although the ordinance has been labeled a "Blueprint for Clean Air,"[171] it has been only partially successful. Its most notable achievement is considered by some to be its regulation of contaminants in fuels. A timetable was established under the ordinance for the use of high-sulfur fuels. This timetable, advanced by almost 2 years, may be the chief accomplishment of the law. Its major shortcoming must be considered the impracticality of enforcing some regulations without creating energy shortages or other social detriments.

The same situation exists within the City of Philadelphia today. Regulations governing use of incinerators were enacted in October of 1969. Recently, the Air Management Services reported that the vast majority of the incinerators are not in compliance, because the City does not know where they are and does not have the personnel to track them down.

In the past 3 years, there has been a proliferation of local ordinances.[172] The tendency toward regulation of fuel characteristics and more stringent enforcement tools, such as direct court actions bypassing an administrative procedure, appear to be most prevalent.

One interesting development is illustrated in the recent Philadelphia Code. It was felt that true regulation could not be obtained without some control over land use because if heavily industrial areas were permitted to expand and high-density population centers to become even denser, further degradation would be inevitable. The result was the granting to the Pollution Control Board of what amounts to a veto power over other city agencies, such as the Planning Commission and the Zoning Board.[173] Whether this will prove an effective approach, only experiences will tell.

C. Other Problems

Another area of state and local regulation in the pollution field that has aroused interest in recent years is the control of ground water.[174] Many states have considered, for example, acid mine drainage but without a definitive resolution. Another problem is the septic tank, where the difficulty seems to be in identifying and finding those that may be causing trouble.

Of overriding concern in all areas is the coordination of efforts in the control of our environment. Examples of need for coordination are many. If a municipal incinerator system cannot be updated or a new system proves too costly, then the logical step would be to establish dumping grounds. Dumping grounds, however, get rained upon, causing water problems. Different areas of the country are subject to differing priorities. In one area, the main problem may be water. In another, the main problem may be air. The common problem is, as always, money and manpower. Efforts should be directed toward increased training, with the objectives of improving competence and reducing administrative costs.

There have been some recent moves toward improved coordination at the federal level with the creation of an Environmental Quality Council[175] and an Environmental Protection Agency. The States of New York, California and Washington have also considered such agencies,[176] and the National League of Cities, at its meeting in San Diego in December of 1969, recommended coordination.[177]

Section 3.
INTERNATIONAL CONSIDERATION OF ENVIRONMENTAL CONSERVATION

Increasingly, the maintenance of a satisfactory environment is being viewed as a matter of concern to the international community and to international organizations of nations. Of course, it should be recognized that there is no common environmental problem that affects all nations in the same manner and degree, but the international community as such has a mutual general interest in environmental conservation.

It is obvious that the more industrialized nations generally have more immediate problems of environment at home than do the developing nations. All nations, however, have an interest in promoting satisfactory quality of international waters and thereby preventing pollution of the high seas as well as pollution of their adjoining territorial waters. And, as would be expected, this is the area to which the international community as such has directed its principal concern. The avenue for international community concern in this regard has been the Inter-Governmental Maritime Consultative Organization (IMCO), a specialized agency of the United Nations (U.N.).

Recently, international organizations of nations are expressing interest in environmental conservation. The Economic Commission for Europe (ECE) has for some years been involved with water pollution in Europe, primarily regarding the major international rivers of Western Europe.

The United Nations and the U.N. Economic & Social Council (UNE&SC) are engaged in studies of environmental problems, with the United Nations initiating planning for a 1972 Preparatory Conference on the Human Environment to be held in Stockholm. It can be expected that all of the nations of the U.N. will be represented.

The North Atlantic Treaty Organization (NATO) at its ministerial conference in December 1969 placed problems of the environment upon its agenda and, within the NATO structure, the Committee on Challenges to Modern Society (CCMS) has organized several conferences to develop multi-nation agreements to eliminate or reduce such problems.

The Organization of Economic Cooperation and Development (OECD), composed of most of the developed nations of the Free World, has carried out extensive surveys of various aspects of environmental conservation.

These activities of international organizations evidence the emerging international-community concern with environmental conservation. A promising element is that these bodies welcome the cooperation of private organizations in their work.

At the same time, however, some nations that are greatly concerned with air and water conservation have initiated unilateral action which raises serious questions of jurisdiction under international law.

Careful and objective investigation and analysis by groups such as the International Law Association could make a significant contribution to the developing policy and law of international organizations and nations regarding transnational environmental matters. Some nations have initiated programs to deal with environmental problems on a domestic basis. There are also international conventions dealing with pollution of the seas by oil and with pollution of some of the great international rivers. Yet it is fair to say that neither nations nor international organizations have truly begun to approach the conservation of our earthly environment on a comprehensive basis.

The growing, though occasionally discordant, international interest and action on environmental conservation prompts the need for a brief review of two fundamentals. First, what are the international aspects of environmental conservation which lead to actions by communities of nations? Second, what is the background and state of relevant international law?

A. International Aspects of Environmental Conservation

As has been described in some detail in Chapter One, geophysicists, ecologists and other scientists emphasize that the earth and its environment constitute a comprehensive and closely interrelated system of which human beings are indeed a significant factor along with air, water, soil, minerals and aminal life. Certainly there exists some sort of balance among these various elements, albeit the tolerances of this balance are quite broad. The danger is that we do not know with any degree of precision what those tolerances are.

So although there is good reason to believe that the damage to our environmental system may be serious, the initial needs are for more and better information as to the extent of this damage and for a more precise and reliable understanding of the interrelationships among the various elements of the system. A study of environmental preservation will require close collaboration by varied disciplines having access to factual data relating to the interrelationships of elements composing our environment.

Despite the environmental damage that has already occurred, there is no agreed authoritative opinion that irreparable harm has been done. To the contrary and notwithstanding the gloomy forecasts of some observers, there is every reason to believe that a coordinated approach on an international basis with properly selected priorities will achieve that conservation of our earth-space environment required to buttress a steadily improving quality of life.

A continuing and steadily improving life quality does not and indeed cannot imply a return to some earlier pastoral era or a back-to-nature movement. The maintenance of an adequate environmental system rather implies an expanding economy that will generate the necessary resources and technology to harmonize the maintenance of that system with an improving life quality. The relevance of this harmonizing of goals was dramatically portrayed at a recent conference of the International Organization of Consumers Unions held in Austria. A director of the Consumers Council in India is reported to have said: "The wealthy countries worry about car fumes. We worry about starvation." And the vice president of the Consumer Association in Malaysia commented: "Some of us would rather see smoke coming out of a factory and men employed than no factory at all. It is, after all, a matter of priority."

These expressions of priority may be contrasted with a passage drawn from the February 1970 message of the President of the United States to the Congress on the environment, in which he said, "Quite inadvertently, by ignoring environmental costs we have given an economic advantage to the careless polluter over his more conscientious rival. While adopting laws prohibiting injury to person or property, we have freely allowed injury to our shared surroundings. Conditioned by an expanding frontier, we came only late to a recognition of how precious and how vulnerable our resources of land, water and air really are."

These views illustrate rather dramatically the difference in fundamental approach to environmental conservation between developed and developing nations as well as some of the problems that will inevitably arise in connection with an effort to deal internationally with conservation.

The point to be drawn, however, is that economic development, including industrialization, and the maintenance of a satisfactory environment are not alternatives. We can certainly have and indeed will have clean industrial plants and automobiles.

Despite these basic differences in degree of economic development and industrialization and differences in environmental degradation and social problems that exist in various countries and regions, it is essential that a comprehensive international approach to conservation of the earth-space environment be initiated. There are certain conservation problems that are global in nature and to be feasibly dealt with require concert among nations. And the converse--unilateral action by many nations to cope with global environmental problems--could but lead to myriad and difficult questions of conflict of laws and conflicts of jurisdiction. Other environmental problems which may be essentially domestic in effect will nevertheless demand a regional, if not global, approach if they are to be effectively resolved. In addition, despite the absence of commonality of environmental conditions among nations, increasingly the maintenance of a satisfactory global environment is being viewed as a concern of the international community.

Thus the threshold task of meeting the concern for development of proper international law in the field of environmental conservation would be to determine the interstices or interfaces, as the case may be, between environmental conservation matters which for effective solution require a comprehensive, transnational approach and others which are subject to satisfactory solution through domestic action by a nation. While there will be no clear line of demarcation between that which is international and that which lies in the domestic field, certain problems can be identified which would lend themselves appropriately to an international solution. Illustratively, the following types of problems appear appropriate for international consideration.

Nations have an interest in promoting a satisfactory quality of international waters both of the high seas and of international drainage basin systems. Pollution of the high seas endangers the quality and resources of the territorial waters of coastal nations and, of course, the shores as well.

IMCO continues to address itself to pollution of the seas. The conventions that IMCO has sponsored (the International Convention for the Prevention of Pollution of the Sea by Oil of 1954, presently in force, and the two 1969 Brussels Conventions which have been opened for ratification) are concerned with pollution of the seas by oil and the question of civil liability arising therefrom. These conventions are reviewed in greater detail later in this section. The point to be made here is that comprehensive examination should be made, for legal purposes, of the conservation of the quality of high seas and the pollution of those waters from whatever cause, including radioactive wastes, excessive nutrients, and the discharge of waste water of extremely high temperature.

Connected with conservation of the quality of the high seas is the interesting question of a coastal nation's jurisdiction to prescribe and enforce its laws outside its territory and territorial waters in order to prevent pollution damage to its territory and to punish those causing such damage. A recently enacted act of the Canadian Parliament, which established "safety control zones" in Arctic waters 100 nautical miles from the Canadian coast above the 60th parallel to protect Canada's territorial waters and coasts from potential pollution by oil from exploration or transport activities, raises a highly significant issue of jurisdiction under international law. In other words, does international law limit a nation's capacity to act unilaterally outside its territory to protect its territory from potential pollution damage? Unquestionably, such issues of jurisdiction should be carefully examined.

The exploration for and production of mineral resources from the subsoil under the high seas is estimated to become increasingly significant in the decades ahead. Here questions arise as to coastal-nation jurisdiction over these minerals and the nature of the international regime to be established in the deep-ocean area seaward of such jurisdiction. Surely these resources should and must be produced for the benefit of the expanding world economy. This production, however, should be harmonized with the maintenance of a satisfactory quality of the surrounding marine environment.

There is an established international obligation among nations to refrain from conduct that would result in environmental damage to another nation by pollution. (See the *Corfu Channel Case*[178] discussed later in this section.)

It goes almost without saying that the earth's airspace or atmosphere is a matter of international concern, and for effective action an international approach will be required. The *Trail Smelter Arbitration* (discussed later) is an illustration of the general principle of nation-to-nation obligation under international laws in matters of atmospheric environmental conservation.[179]

In connection with consideration of airspace and atmospheric quality, and the total earth-space environment for that matter, weather and climate are of the utmost significance. Agricultural productivity is heavily and directly dependent upon weather and climate. There are indications that certain activities which could affect rainfall and climate are progressing rather rapidly. Does or should international law restrict or prohibit the conduct of a nation that would cause weather or climate change affecting other nations?

Quite recently, reports have been issued which raise two uncertainties about possible atmospheric effects of supersonic aircraft operations. The first is that the operation of jet aircraft at 1,800 miles per hour could inject water vapor into the stratosphere to such an extent that increased winter cloudiness in the polar regions might occur. Secondly, large numbers of supersonic aircraft operated on fuels today utilized by jet aircraft could raise stratospheric temperatures. On the basis of these reports, a group of scientists recently requested continued delay in beginning large-scale operation of supersonic transport planes until questions about their effect upon the environment can be answered.

Such a description of earth-space environmental problems of a transnational nature could be continued, but this report only attempts to indicate in brief the need for an international rather than a purely domestic approach to this category of problems. This is not to say that the earth-space environment could not be improved upon, perhaps adequately, through domestic action. However, concerted action among nations would provide a more effective approach.

Accordingly, governments and international organizations, with the assistance of experts in environmental sciences, will over the months ahead be examining categories of problems that lend themselves to international or regional consideration. They will review existing conventional and customary international law for suggested means for resolution of critical problems of this nature, consider whether new draft treaties would be helpful to nations and, if the answer is affirmative, perhaps begin preparation of drafts. In these efforts, the experience of industry and its role must be taken fully into account if the resulting agreements are to have balanced and optimum effectiveness.

B. General Principles of International Law

Although no body of customary international law has developed that relates precisely to environmental conservation, there do exist some general principles that by analogy have a bearing on that subject.

The basic principle of international law is that a nation is generally limited in taking action that would cause injury within the territory of another nation. In the *Corfu Channel Case*, the International Court of Justice stated that international law requires every nation "not to allow knowingly its territory to be used for acts contrary to the rights of other States." This principle is a reflection of the maxim *sic utere tuo ut alienum non laedas*; that is, "one must so use his own as not to do injury to another." This basic principle underlies the range of nation-to-nation relationships, and problems of pollution and the environment are surely no exception.[180]

The *Trail Smelter Arbitration* between the United States and Canada illustrates the general international principle of nation-to-nation obligation in environmental conservation matters. In that case Canada was found responsible for the injury and damage resulting in the United States from fumes emitted from a smelter located in British Columbia and deposited over a large area of the State of Washington. The Tribunal concluded that, "under the principles of international law, as well as of the law of the United States, no nation has the right to use or permit the use of its territory in such a manner as to cause injury by fumes in or to the territory of another or the property of persons therein."[181]

Thus it can be concluded that there is a general international obligation among nations to refrain from conduct that would result in pollution to or within the territory of other nations. This is, of course, an exceedingly general obligation and, as will be seen, is given definition and precision by treaty as the occasion requires.

C. Treaties and Conventions

Those international agreements dealing with oil and gas operations and environmental conservation that have been concluded are directed toward pollution of the seas. They are discussed below.

1. The Geneva Convention on the High Seas

Article 24 of the Geneva Convention on the High Seas provides that:

> Every State shall draw up regulations to prevent pollution of the seas by the discharge of oil from ships or pipelines or resulting from the exploitation and exploration of the seabed and its subsoil, taking account of existing treaty provisions on the subject.

The import of this provision is to obligate nations party to the Convention to prescribe laws or regulations to prevent pollution of the seas from petroleum operations, including exploration and production and transport by pipeline or ship. Although not specified in Article 24, it must be assumed that the laws or regulations to be prescribed would be applicable only to persons, vessels or areas subject to the jurisdiction of the prescribing nation.

The Geneva Convention on the High Seas entered into force on September 30, 1962, and the United States deposited its instrument of ratification on April 12, 1961. As of December 31, 1970, forty-seven nations have ratified or acceded to it.

2. International Convention for the Prevention of Pollution of the Sea by Oil, 1954 and 1962

On May 12, 1954, at the London Conference on Pollution of the Sea by Oil, the participating nations signed, subject to ratification, this Convention, which came into force on July 26, 1958, and was ratified by the United States, subject to reservations and an understanding, on September 8, 1961. On December 31, 1970, forty-two nations had ratified or accepted this Convention.

The principal obligations accepted by party nations under that Convention, as amended by the 1962 Convention for the Prevention of Pollution of the Sea by Oil, which apply to seagoing ships with certain exceptions not of importance here, follow:

> Tankers of 150 gross tons or over and all other ships of 500 gross tons or over are prohibited from discharging in certain zones of the oceans oil or any oily mixture the oil of which fouls the surface of the sea, except in cases involving safety of the ship, cargo or life.
>
> Ships are required to carry and make available for inspection an oil record book in which are entered details on ballast handling, tank cleaning and slop disposal. Provisions are included, among others, for vessel equipment--both as to existing vessels and new construction. Violation is made an offense under the laws of the country in which the vessel is registered.

The International Convention for the Prevention of Pollution of the Sea by Oil, 1962, amended the 1954 Convention in various respects, including a redefinition of the types and sizes of ships regulated, a redefinition of the extent to which ships must record the discharge of oil, a new definition and formula in respect to an oily mixture, an extension of certain zones in which the discharge of oil is prohibited, a revision in amendment procedures and provisions relating to adequate disposal facilities, and other necessary changes.

The Congress of the United States enacted legislation in 1961 to implement the provisions of the International Convention for the Prevention of the Pollution of the Sea by Oil. This Act makes violation of its terms a misdemeanor. It further provides that ships other than those owned and operated by the United States may be denied port clearance until the pecuniary penalty imposed by a conviction for violation of the Act is paid and that the penalty shall constitute a lien upon the offending vessel.[182]

3. 1969 Brussels Conference on Marine Pollution Damage--Draft Conventions

In November of 1969, the Assembly of the Inter-Governmental Maritime Consultative Organization convened a conference of nations in Brussels to consider the adoption of a convention or conventions on questions relating to marine pollution damage.

The Conference prepared and opened for signature and accession the following:

1. The International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties.

2. The International Convention on Civil Liability for Oil Pollution Damage.

The former would provide that party nations "may take such measures on the high seas as may be necessary to prevent, mitigate or eliminate grave and imminent danger to their coastline or related interests from pollution or threat of pollution of the sea by oil, following upon a maritime casualty or acts related to such a casualty, which may reasonably be expected to result in major harmful consequences." This provision is of course directed towards a situation in which a serious casualty has occurred, and action by an endangered coastal nation, taken on the high seas, may prevent or mitigate damage to it.

Except in cases of extreme urgency, a coastal nation prior to taking such action is required to consult with other affected nations and notify persons whose interests may be affected, and take into account any views that they may submit.

Measures taken by a coastal nation are required to be proportionate to the threatened or actual damage and are not to exceed the extent necessary to prevent pollution under the circumstances.

This Convention will enter into force on the 90th day following the date on which governments of 15 nations have ratified or accepted it.

The second of the 1969 Brussels Conventions, focusing on Civil Liability for Oil Pollution Damage, would, if it enters into force, "apply exclusively to pollution damage caused on the territory including the territorial sea of a Contracting State and to preventive measures taken to prevent or minimize such damage." Thus, applicability of the Convention is based upon the place of damage, i.e., the territory of a nation. The owner of a ship would be liable for any pollution damage caused by the escape or discharge of oil from the ship as a result of an occurrence causing such damage, except in the following cases: (1) act of natural phenomenon or of war, (2) negligence or wrongful act of a government or authority responsible for lights or other navigational aids in regard to such lights or aids, and (3) act or omission of a third party performed with intent to cause damage.

In a case of pollution damage subject to the Convention, the ship owner's liability for one incident would be limited to a total amount of 2,000 French francs (about $134) for each ton of the ship's tonnage, not to exceed 210 million French francs (about $14 million). On the other hand, if the owner were actually at fault, this limitation of liability would not be available to him.

While this Convention is inapplicable to warships, party nations agree that they will waive the defense of sovereign immunity with respect to their ships used for commercial purposes.

Ratification by 8 nations, 5 of which each has not less than 1 million gross tons of tanker tonnage, will effectuate the Convention.

The 1969 Brussels Conference enacted the following resolutions:

1. Requesting that IMCO prepare a draft for a compensation scheme based upon the existence of an international fund and convene an international conference on the subject not later than the year 1971.
2. Requesting that IMCO intensify its work on all aspects of pollution by agents other than oil.

Both of these draft conventions were signed on behalf of 16 nations, including the United States. The ratification and effectuation process will require considerable time for basic concepts of liability as between cargo owner and ship owner, as well as the basis and extent of liability are involved.

D. International Resolutions and Executive Agreements

In an effort to move toward treaties or agreements of a less formal nature, nations typically initiate resolutions by an existing intergovernmental group. The United Nations and its specialized agencies provide a normal forum for such activities. The planned 1972 U.N. Preparatory Conference on the Human Environment, mentioned earlier, is an example.

Another, more recently developed forum, through which the United States is making several far-reaching proposals concerning pollution by oil, is the Committee on Challenges to Modern Society, which is associated with NATO. The interaction of the interests of this group with those of IMCO is apparent from the conclusions and recommendations developed by participants, including representatives of the United States, in a CCMS Oil Spills Conference in November 1970.

The nations resolved to achieve, by mid-decade, the elimination of intentional and the minimization of accidental discharges of oil, through, but not limited to, the following:

- Encouraging the universal and rapid ratification of (a) The International Convention for Prevention of Pollution of the Sea by Oil, 1954, and its 1962 amendments; and (b) the 1969 amendments to the International Convention for Prevention of Pollution of the Sea by Oil, 1954, agreed to at the Brussels Conference. Further, urging the adoption of the latter as guidelines for national legislation prior to international enactment.
- Supporting and accelerating work of international organizations such as IMCO on the development of equipment and procedures for ship safety, for measuring and controlling the oil content of discharges, and for port facilities for oily wastes.
- Urging the convening of a special IMCO session in 1971 to prepare treaty regulations prohibiting all intentional discharges of oil and oily wastes into the sea.
- Providing measures for the elimination of open-water pollution by oil-transfer facilities, including provisions for review of national policies, involving government and industry, of techniques and enforcement.

- And further, developing appropriate National Oil-Spill Contingency Plans to include (a) the designation of coastal oil spill control centers; (b) the requirement of flag vessels and aircraft to report to the designated centers any accident or situation which is or has the potential for discharging oil; and (c) the cooperation and exchange of information between centers and nations to minimize environmental damage.

A point of importance in international consideration of environmental problems is to ensure that resolutions and more formal actions are developed and implemented by the body most qualified to do so from the point of view of applicable expertise. Technical problems are best solved by groups constituted specifically to deal with such problems. The same is true for legal, scientific or economic problems. Although international action is ultimately taken by the participating governments, they should do so with the full cooperation of those elements of the private sector having relevant experience and expertise.

Regarding problems of environmental conservation and pollution control that are clearly of international concern, thereby involving the interests of many nations, the desirable approach should be to reach broadly based agreement among nations so that conflicting unilateral regulations by many nations would be avoided.

Part II

Industry Operations

Chapter Three

THE FUNDAMENTALS OF INDUSTRY OPERATIONS

The purpose of this and subsequent chapters concerned with oil industry operations is to provide (1) a basic description of these operations and (2) an assessment of the problems faced by management in its efforts to meet public needs for both energy and environmental quality.

Section 1.
OPERATIONS: THEIR NATURE, SCOPE AND EVOLUTION

The U.S. petroleum industry is comprised of more than 40,000 companies engaged in finding, producing, transporting, processing and marketing oil and gas and the products made from them. Collectively these companies employ about 1.5 million people and, with assets of $71 billion, constitute the Nation's third largest industry.[183]

Some of these companies are engaged exclusively in one facet of industry operations (e.g., production, refining, marketing, transportation). These companies, whatever their size, are known as "nonintegrated" companies. Others, called "integrated" companies, engage in all phases of the business and often operate throughout the world, while in between are those "semi-integrated" companies with two or more types of operation.

In terms of its total assets of $71 billion,[184] this aggregation of companies, identified as the "petroleum industry," is the third largest industry in the United States, exceeded only by agriculture and the combined public utilities. (Note: This figure places gas companies in the category of public utilities with electric power and communications.)

Supplying petroleum energy is not only the endeavor of a wide variety and large number of companies (excluding service station dealers), it is the endeavor of many individual Americans in every state of the Union and in most countries throughout the world. In the United States alone, petroleum companies employ approximately 1.5 million people,[185] providing a source of direct personal income for nearly 1 out of every 50 persons in the U.S. labor force.

A. Exploration and Production

An extensive drilling effort is required to find and develop adequate oil and gas resources, and a large portion of that effort results in dry holes (see Table 8).

While oil and gas are produced in 32 of the 50 states, only about 1.4 percent of the total land area of the country (31,309,585 acres) has proved so far to be productive.[186] At the end of 1970, there were 642,607 producing wells in the United States, of which 517,177 were oil wells and 125,430 were gas wells.[187]

Total U.S. production of crude oil in 1970 averaged almost 9.2 million barrels per day (Table 9).[188] A 1968 Bureau of Mines report projected 1975 and 1980 production requirements at 10.1 and 11.4 million barrels per day, respectively.[189] An analysis of more recent trends and projections, however, shows domestic production peaking out at 10.1 million barrels per day in 1980.[190] This shortfall in production plus increases in total domestic demand estimates (listed on p. 17) will require increased imports, with parallel increases in tanker transportation of oil and the threat of pollution from such tankers.

The marketed quantity of domestic natural gas produced in 1970 was 22.0 trillion cubic feet.[191]

TABLE 8

REVIEW OF DRILLING OPERATIONS FOR 1969 & 1970

Type of Well	Number of Wells Drilled			
	1969		1970	
	Exploratory	Total	Exploratory	Total
Oil	1,084	14,368	850	13,750
Gas	616	4,083	550	4,050
Dry	8,001	13,736	7,000	11,650
TOTAL	9,701	32,187	8,400	29,450
TOTAL FOOTAGE DRILLED	157,107,859		145,160,000	

Source: American Petroleum Institute, News Release (January 10, 1971).

TABLE 9

REVIEW OF PRODUCTION FOR 1969 & 1970 PETROLEUM LIQUIDS

Type of Product	Daily Average Number of Barrels	
	1969	1970
Domestic Crude	8,778,071	9,176,775
Domestic Lease Condensate	459,603	454,822
Domestic NGL	1,589,701	1,680,085
Other Hydrocarbon	11,543	17,090
TOTAL U.S. PRODUCTION	10,838,918	11,328,772

Source: U.S. Bureau of Mines, "Crude Petroleum, Petroleum Products and Natural Gas Liquids, December, 1970," *Mineral Industry Surveys* (Monthly Petroleum Statement, published March 23, 1971).

A 1969 survey indicated that there were 840 gas-processing plants (normally considered a part of the production phase of the industry), with a total production of 70,061,030 gallons of products per day.[192]

The industry's ability to maintain and expand its producing capacity depends on both a continuing program of exploring for new reserves and a developing technology for improving reservoir performance and production operations. In this report, special emphasis will be given to the discovery of new reserves through offshore operations, because of their increasing importance and because of the inherent possibilities for pollution.

Offshore areas now account for about 17 percent of the Nation's total domestic crude oil supply, even though practical methods for drilling and producing in offshore waters have been developed entirely since the end of World War II, and the proportion of U.S. domestic crude demand supplied from offshore operations will continue to grow. The historic trend in offshore activity is shown in Figure 5.

Several technical improvements have helped increase productive capacity in recent years, offshore and onshore. These include hydraulic fracturing and the accelerated application of fluid injection. Other important factors include extensive use of unitized operations. Unitized operations and wider spacing have permitted the production of oil reservoirs with fewer wells, with consequent major savings in costs and the development and continued production of otherwise uneconomic fields. These and other technological advances have materially reduced the possibility of accidental pollution of land and water.

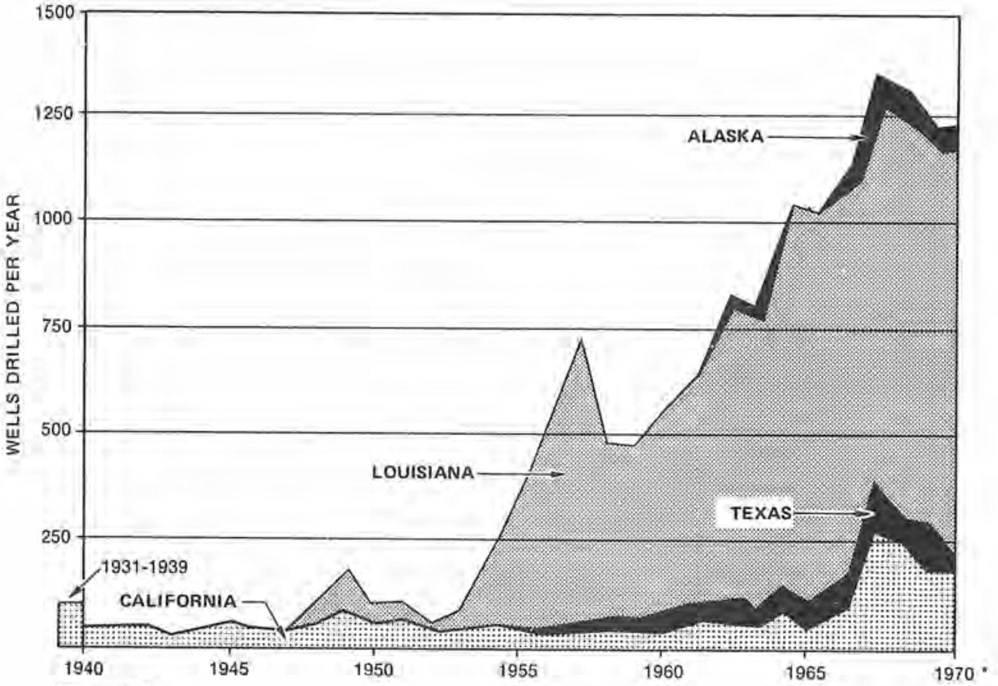

Figure 5. Annual Offshore Drilling on U.S. Continental Shelves. More than 14,000 Offshore Wells Drilled through 1970.

B. Refining

As of January 1, 1971, the United States had 279 petroleum refineries* with a total crude oil distillation capacity (operating and shutdown) of 13,019,978 barrels per calendar day (B/CD). Individual capacities ranged from less than 1,000 to 434,000 B/CD.[193] All have waste-water treating systems to handle various types of liquid and solid wastes. The geographic distribution of U.S. refineries, an important consideration in evaluating the impact of refining on the Nation's total pollution problem, is shown in Table 10 and Figure 6.

It is also significant that while U.S. crude oil distillation capacity (operating and shutdown) had increased 31.5 percent over the 9,901,424 barrels reported for January 1, 1960, the total number of refineries was 11 percent less than the 310 on January 1, 1960.[194] Many of the smaller and older plants--generally the ones with less effective waste-control systems--are being dismantled as the trend toward larger, more efficient refineries continues.

The concentration of U.S. refining capacity in relatively few large refineries is illustrated in Figures 7 and 8. The 10 largest refineries process over one-quarter of the crude oil in the United States, with the top 20 processing two-fifths, and the largest 30 handling one-half. The mean capacity of operating refineries as of January 1, 1971, was slightly over 50,000 B/CD, while the median capacity was 25,000 B/CD.

Refineries are operated in 39 states (Figure 6); however, in an effort to reduce transportation costs, over three-fourths of the total U.S. capacity has been located in eight states, and over one-half is in three states. The following chart shows the percentage of concentration of U.S. refining capacity in eight major states, interpreted from the figures given in Table 10.

State	No. of Refineries	Crude Capacity Thousand B/CD	Crude Capacity as % of Total	Cumulative %
Texas	45	3,444	27.2	27.2
California	35	1,702	13.4	40.6
Louisiana	17	1,308	10.3	50.9
Illinois	11	868	6.9	57.8
Pennsylvania	12	650	5.1	62.9
Indiana	9	600	4.7	67.6
New Jersey	6	520	4.1	71.7
Ohio	6	514	4.1	75.8
TOTAL	141	9,606	75.8	

This geographic concentration of the petroleum refining industry is an important factor to be considered in evaluating the impact of the refining industry on the overall pollution problem of the United States.

Other indications of the scope of refining operations are the economic investment they represent and the value of their products.

Processing facilities in these refineries represent an investment of more than $11 billion.[195] The investment in new refining facilities has been projected at $900 million to $1.2 billion for the next 5 years.[196]

The products shipped from these refineries have been valued at more than $19 billion per year,[197] and this value is expected to grow to more than $22 billion per year by 1974. In 1970, liquid petroleum products and natural gas supplied 76 percent of the total energy requirements of the United States;[198] approximately one-half of this portion was from U.S. refined products.

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*Volume I figures have been modified slightly by Bureau of Mines' final year-end data released September 14, 1971.

TABLE 10

NUMBER AND CAPACITY OF PETROLEUM REFINERIES IN THE UNITED STATES AND PUERTO RICO BY BUREAU OF MINES REFINING DISTRICTS, PAD DISTRICTS AND STATES

JANUARY 1, 1971

Refining District, PAD District and State	Petroleum Refineries (Number)			Crude Oil Distillation* Crude oil throughput capacity (Barrels per calendar day)					Cracking, Reforming, Coking and Alkylation Gasoline output capacity† (Barrels per calendar day)				
					Shutdown					Shutdown			
	Total	Operating	Shutdown	Operating	Operable	Inoperable	Total	Building	Operating	Operable	Inoperable	Total	Building
Refining District:													
East Coast	18	18	-	1,341,000	-	-	1,341,000	60,000	571,550	20,700	-	592,250	68,400
Appalachian No. 1	12	12	-	160,420	-	-	160,420	9,300	63,025	852	-	63,877	-
Appalachian No. 2	2	1	1	60,000	-	24,000	84,000	-	23,550	-	10,270	33,820	-
Ind.-Ill.-Ky., etc.	46	37	9	2,264,270	117,730	68,750	2,450,750	160,000	1,107,812	37,700	35,100	1,180,612	93,700
Minn., Wisc., etc.	7	6	1	238,900	6,600	-	245,500	-	96,650	1,300	-	97,950	-
Okla., Kansas, etc.	27	26	1	929,500	3,900	-	933,400	-	457,515	4,400	1,250	463,165	11,750
Texas Inland	24	20	4	415,978	14,400	13,500	443,878	-	208,850	2,700	10,450	222,000	-
Texas Gulf	27	25	2	3,027,700	36,200	48,500	3,112,400	127,000	1,417,855	4,480	2,350	1,424,685	129,700
Louisiana Gulf	15	14	1	1,558,300	6,500	-	1,564,800	165,600	742,290	-	-	742,290	161,400
Ark.-La. Inland, etc.	19	18	1	182,080	2,400	-	184,480	700	66,600	-	-	66,600	-
New Mexico	6	5	1	43,200	1,000	-	44,200	-	17,750	-	-	17,750	-
Rocky Mountain	30	26	4	425,300	8,750	5,000	439,050	-	192,835	7,450	600	200,885	8,800
West Coast	46	45	1	2,011,600	4,500	-	2,016,100	108,000	1,062,425	3,400	16,095	1,081,920	134,450
PAD District & State:													
District I:													
Delaware	1	1	-	140,000	-	-	140,000	-	67,100	-	-	67,100	15,900
Florida	1	1	-	3,300	-	-	3,300	-	-	-	-	-	-
Georgia	2	2	-	8,900	-	-	8,900	-	-	-	-	-	-
Maryland	2	2	-	19,000	-	-	19,000	-	-	-	-	-	-
New Jersey	6	6	-	519,800	-	-	519,800	60,000	199,950	-	-	199,950	18,200
New York	2	2	-	92,000	-	-	92,000	-	39,100	-	-	39,100	-
Pennsylvania	12	12	-	650,320	-	-	650,320	9,300	301,275	21,552	-	322,827	34,300
Rhode Island	1	1	-	7,500	-	-	7,500	-	-	-	-	-	-
Virginia	1	1	-	51,400	-	-	51,400	-	24,000	-	-	24,000	-
West Virginia	2	2	-	9,200	-	-	9,200	-	3,150	-	-	3,150	-
TOTAL	30	30	-	1,501,420	-	-	1,501,420	69,300	634,575	21,552	-	656,127	68,400
District II:													
Illinois	13	11	2	867,970	78,730	50,000	996,700	160,000	477,200	16,700	26,700	520,600	93,700
Indiana	11	9	2	599,500	4,500	1,500	605,500	-	228,410	3,800	-	232,210	-
Kansas	11	11	-	376,000	3,000	-	379,000	-	182,615	3,500	1,250	187,365	-
Kentucky	4	4	-	156,500	500	-	157,000	-	64,200	-	-	64,200	-
Michigan	10	7	3	158,800	11,500	17,250	187,550	-	68,340	2,400	8,400	79,140	-
Minnesota	3	3	-	151,500	-	-	151,500	-	64,650	-	-	64,650	-
Missouri	1	1	-	83,000	-	-	83,000	-	38,400	-	-	38,400	-
Nebraska	1	1	-	5,000	-	-	5,000	-	2,200	-	-	2,200	-
North Dakota	2	2	-	53,400	1,600	-	55,000	-	21,900	1,300	-	23,200	-
Ohio	9	6	3	513,500	22,500	24,000	560,000	-	285,162	14,800	10,270	310,232	-
Oklahoma	14	13	1	465,500	900	-	466,400	-	234,300	900	-	235,200	11,750
Tennessee	1	1	-	28,000	-	-	28,000	-	8,050	-	-	8,050	-
Wisconsin	2	1	1	34,000	5,000	-	39,000	-	10,100	-	-	10,100	-
TOTAL	82	70	12	3,492,670	128,230	92,750	3,713,650	160,000	1,685,527	43,400	46,620	1,775,547	105,450
District III:													
Alabama	6	4	2	32,350	7,900	-	40,250	-	1,200	-	-	1,200	-
Arkansas	6	6	-	92,000	-	-	92,000	-	40,500	-	-	40,500	-
Louisiana	17	17	-	1,307,530	1,000	-	1,308,530	166,300	660,690	-	-	660,690	108,600
Mississippi	5	5	-	308,500	-	-	308,500	-	106,500	-	-	106,500	52,800
New Mexico	6	5	1	43,200	1,000	-	44,200	-	17,750	-	-	17,750	-
Texas	51	45	6	3,443,678	50,600	62,000	3,556,278	127,000	1,626,705	7,180	12,800	1,646,685	129,700
TOTAL	91	82	9	5,227,258	60,500	62,000	5,349,758	293,300	2,453,345	7,180	12,800	2,473,325	291,100
District IV:													
Colorado	5	4	1	45,950	5,000	-	50,950	-	18,750	1,750	-	20,500	-
Montana	10	8	2	124,750	3,750	-	128,500	-	61,440	5,700	600	67,740	8,800
Utah	5	5	-	117,100	-	-	117,100	-	50,145	-	-	50,145	-
Wyoming	10	9	1	137,500	-	5,000	142,500	-	62,500	-	-	62,500	-
TOTAL	30	26	4	425,300	8,750	5,000	439,050	-	192,835	7,450	600	200,885	8,800
District V:													
Alaska	2	2	-	37,500	-	-	37,500	-	-	-	-	-	-
California	36	35	1	1,701,900	4,500	-	1,706,400	10,000	965,945	3,400	16,095	985,440	73,200
Hawaii	1	1	-	35,000	-	-	35,000	-	11,680	-	-	11,680	-
Nevada	1	1	-	800	-	-	800	-	-	-	-	-	-
Oregon	1	1	-	12,000	-	-	12,000	-	-	-	-	-	-
Washington	5	5	-	224,400	-	-	224,400	98,000	84,800	-	-	84,800	61,250
TOTAL	46	45	1	2,011,600	4,500	-	2,016,100	108,000	1,062,425	3,400	16,095	1,081,920	134,450
UNITED STATES TOTAL	279	253	26	12,658,248	201,980	159,750	13,019,978	630,600‡	6,028,707	82,982	76,115	6,187,804	608,200‡
Puerto Rico	2	2	-	152,800	-	-	152,800	75,000	59,250	5,900	-	65,150	-
UNITED STATES & PUERTO RICO TOTAL	281	255	26	12,811,048	201,980	159,750	13,172,778	705,600‡	6,087,957	88,882	76,115	6,252,954	608,200‡

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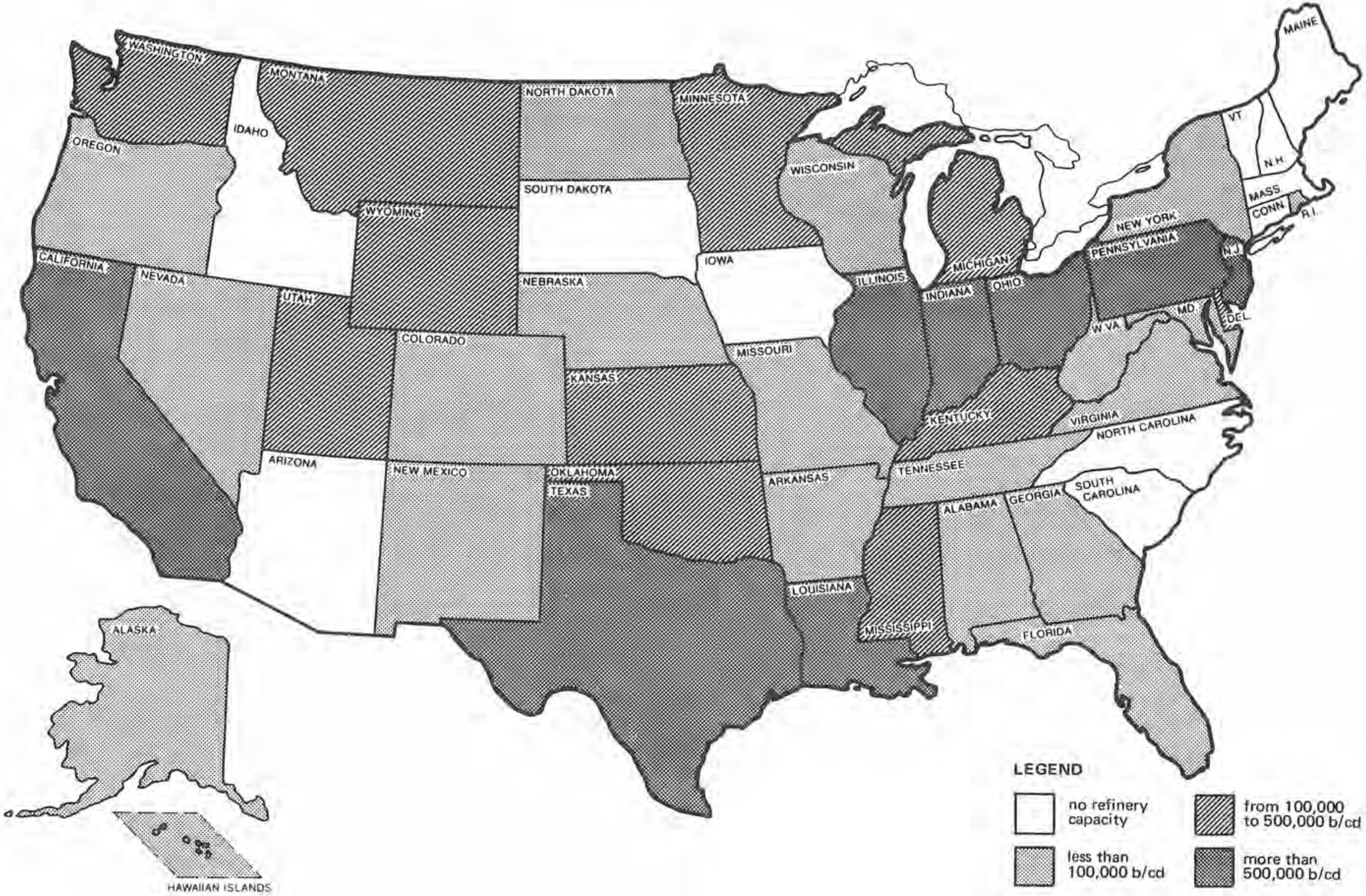
* Includes a small amount of crude oil charged directly to cracking units.

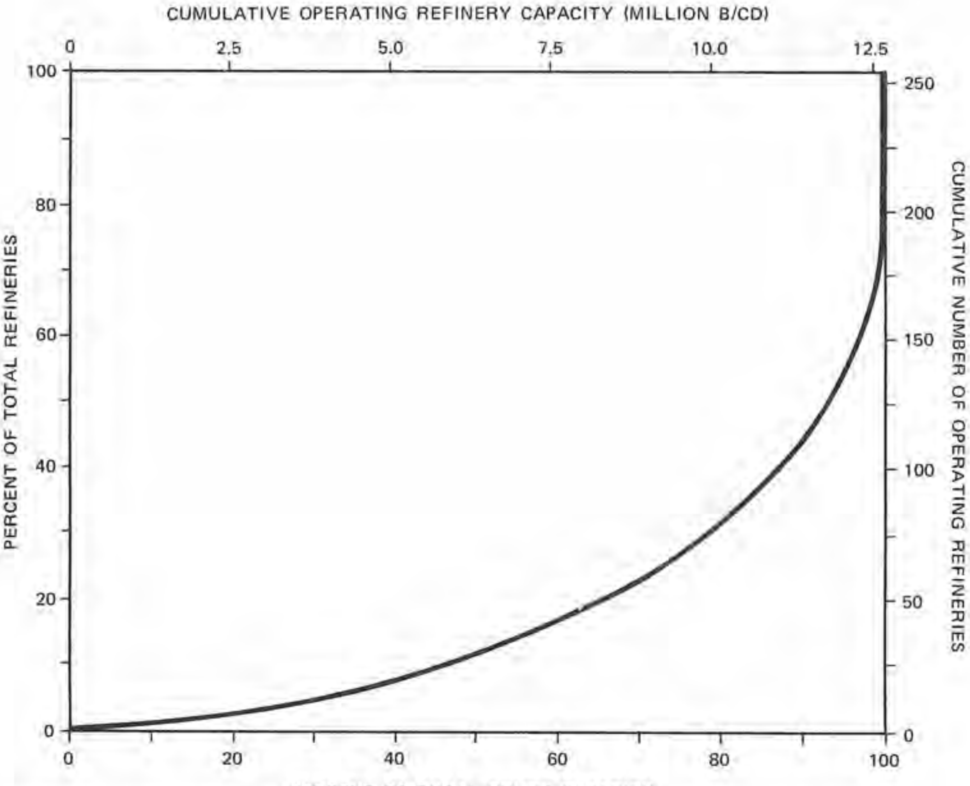
† Capacity expressed in terms of gasoline production.

‡ Includes capacity under construction for replacement, in barrels per day. Crude oil distillation: Pennsylvania, West, 9,300; and for cracking, reforming, coking and alkylation: Montana, 3,400; Oklahoma, 4,500; Pennsylvania, East, 12,000; and Texas Gulf, 27,000. All other figures represent additional capacity under construction.



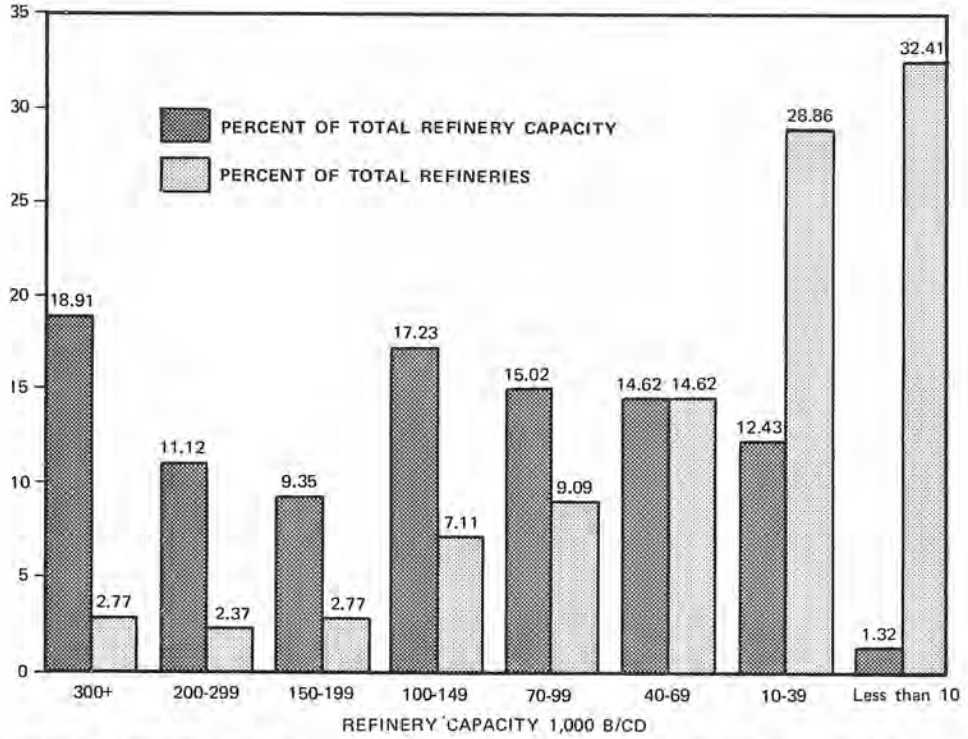
Source: U.S. Bureau of Mines, "Petroleum Refineries in the United States and Puerto Rico, January 1, 1971," *Mineral Industry Surveys* (Petroleum Refineries, Annual, published September 14, 1971).

Figure 6. U.S. Refinery Capacity, By States, 1/1/71.



Source: U.S. Bureau of Mines, "Petroleum Refineries in the United States and Puerto Rico, January 1, 1971," *Mineral Industry Surveys.*

Figure 7. Cumulative Operating Refinery Capacity.



Source: U.S. Bureau of Mines, "Petroleum Refineries in the United States and Puerto Rico, January 1, 1971," *Mineral Industry Surveys.*

Figure 8. Operating Refineries and Their Capacities.

As for personnel, the payroll of the refining segment of the industry was valued at $960 million in 1967 for 106,000 employees.

More than 3,000 products are made wholly or in part from petroleum, and many more are made in the petrochemicals industry. The mix of products from industrial refineries varies considerably because of differences in market requirements, type of crude and type of processing, but on a national basis, the major products and their approximate percentage of total refinery yields are as follows:

Products	% Yield
Gasoline	44.8
Kerosine	2.8
Jet Fuel	7.6
Gas Oil and Distillates	22.2
Residual Fuel Oil	7.6
Other Products and Plant Fuels	15.0
TOTAL	100.0

C. Storage, Transportation and Marketing

A large and efficient distribution system is the key to supplying the Nation with adequate amounts of petroleum. Storage, transportation and marketing facilities and technology have improved in the interests of greater efficiency, safety and convenience; these improvements have often resulted in more effective conservation of the environment.

1. Storage

The petroleum industry requires storage facilities for tremendous volumes of raw materials and products: tanks for crude and refined oils, pressure vessels for natural gas products, and underground storage or cryogenic storage for liquefied gases.

U.S. stocks of crude oil and products at the end of 1970 were estimated at more than 1,017 million barrels,[199] but that represents only part of the total volume of tankage required during production, processing, transportation and marketing.

Underground storage capacity for liquefied petroleum gas (LPG) in the United States in late 1968 was 152 million barrels. At the same time there were 315 underground reservoirs for natural gas, with a capacity of 4.8 trillion cubic feet, and as of June 1, 1969, ten storage facilities for liquefied natural gas (LNG) were operating with a total capacity of 4.6 billion cubic feet. Eight more LNG facilities had been proposed, with additional capacity of 12.4 billion cubic feet.[200]

While various forms of storage such as wooden tanks and earthen pits were once common, steel tanks have long been the main form of petroleum storage. However, changes in storage technology have been taking place as the industry searches for cheaper, safer, cleaner ways to store the necessary inventory of crude and products. Not only have new forms such as underground caverns and refrigerated storage appeared, but continued improvements in design and construction of steel tanks have taken place.

Welded tanks had become the standard by the end of World War II, but improvements in materials, design and construction techniques have helped to keep the cost of storage down while improving its quality. Higher-strength steels have made possible construction of larger tanks, some exceeding 600,000 barrels capacity. Development of field X-ray techniques, which made high quality field weld inspection possible, has led to use of high-joint efficiency in design and hence to savings in metal required for a given tank. Improvements in the design of floating-roof tanks, and in particular the development of internal floating roofs for cone-roof tanks, have enhanced the ability of steel storage to minimize evaporation losses and to conserve the value of products stored. Highly superior exterior and interior protective coatings have appeared since the war. The coatings not only reduce the cost of corrosion, but also assist in the protection of quality of sensitive products such as aviation turbine fuel.

Volatile products such as propane and butane have come into widespread use for heat and petrochemical feedstocks. As a result, the industry has had to develop economic means of storing these products. Since propane and butane have high vapor pressures at atmospheric temperatures, high-pressure storage vessels are required. Large steel tanks for these pressures (up to about 250 psig) are expensive, and it became clear early that new storage technology would be required. The first method developed was to store these materials as liquids under pressure in caverns in earth's crust, i.e., in a situation not wholly unlike that in which nature had produced them. Large caverns, up to 800,000 barrels, have been produced. Most of these have been formed by leaching of salt beds or domes. In areas where suitable salt layers are not available, caverns have been mined in limestone, shale and granite. In addition, some naturally porous media such as depleted oil and gas sands or water sands are being used.

A second method of storing highly volatile products such as propane and butane, and even liquefied natural gas, is to cool them sufficiently so that they are liquid at atmospheric pressure; low-pressure vessels of appropriate design will then be adequate. Two basic types of vessels for this purpose have been designed: insulated, double-walled, aboveground steel vessels up to 250,000 barrels capacity and frozen-earth pits up to 500,000 barrels capacity. For the aboveground case, appropriate steels and superinsulations are used to construct storage tanks in which the evaporation losses are acceptably low. In the frozen pits, a refrigeration system is used to freeze the soil surrounding the pit into an impermeable layer. The cold liquid then maintains the soil frozen. In both types of storage, the evaporation of a portion of the liquefied gas serves to chill the remainder of the liquid. Sometimes refrigeration plants are provided to recondense the evaporating vapors; in other cases, the vapors are fed directly into a gas transmission system.

Major savings in the operation of tank farms in refineries and terminals have come about through application of automatic and remote supervisory control systems. By their very nature, large storage facilities are spread over large areas, with individual units widely spaced. Many men are required to gauge tanks and to operate valves and pumps because of the dispersion of the equipment. Such facilities lend themselves to large savings by installation of remote reading gauges and remote controls for operating valves and pumps. The industry has been eager to garner these savings. Consequently, automation has been and is being widely applied to tank-farm operation.

For some years prior to World War II, the industry had realized that important product values could be lost through evaporation while crude or products were in storage. The value of reflective paint in reducing tank temperatures had been recognized, but not widely adopted since adequate paints were not available. Floating-roof tanks, in their more primitive forms, had been introduced. Open storage was already disappearing.

After the war, the trend toward product conservation was greatly accelerated. Tank designs were improved and adequate paints developed. New vapor-conservation systems were introduced and in some cases compressors were installed to recover quantitatively all vapors from the storage tanks. While the floating-roof tank had already been introduced for storage of volatile crudes and products, it was at war's end not nearly so highly developed as it is today. Better flotation systems, drains and edge seals have been introduced in the last 20 years. Some of these, such as better edge seals, have depended on the postwar development of new materials of superior quality. Internal floating roofs of plastic or aluminum are now in use in cone-roof tanks. These designs bring the advantages of the floating roof to the many cone-roof tanks already in existence. Furthermore, they allow the combination of the conservation characteristics of the floating roof with the quality preservation characteristics of a fixed roof.

Vapor conservation systems have been developed since the war. These are of two general types: the gasholder and the compressor systems. In the gasholder type, a variable volume vapor space is provided so that vapors from one or more tanks may be displaced into and out of this space as the tanks are filled or emptied or change temperatures. Both rigid gasholders similar to those used in the gas industry and flexible membranes in hemispherical domes on the tank roof are used. In other cases the vapors are removed to a compressor which reliquefies them and injects them into a suitable reservoir or stream. Although the primary purpose and principal cost of the compressor system is for pollution control, resulting product recovery may have some economic return.

The rise in the use of aviation fuels following the war imposed new demands on storage facilities. Aviation turbine fuel must be delivered in much cleaner form than was allowable for prewar aviation products. New storage technology had to be developed to protect the product quality. Fully covered, internal floating-roof tanks are used for this service. Internal tank coatings have been developed to limit the pickup of rust particles by the stored product.

2. Transportation

Crude oil, gas and other petroleum products used in the United States move by pipeline, barge, railroad tank car, tank truck and marine tanker, with economics the main factor in determining which mode is used.

Crude oils are transported from the producing fields to refineries and terminals, petroleum products are moved from refineries to distribution terminals, natural gas is piped from the fields to the 49 continental states for distribution to the customer, and LPG is moved from natural gasoline plants and refineries to petrochemical plants and distribution terminals.

The percent of total crude oil and refined products transported in the United States is given in Table 11 by mode of transportation.

Other factors being equal, the benefits of economies of scale are as applicable to petroleum operations as they are to other areas of the economy and ultimately result in cost savings to the consumer. For example, large pipelines, huge marine tankers, and jumbo tank trucks and rail tank cars are now needed. Indicative of the savings through increased size is an estimate that the transportation cost per barrel for a tanker run from the Gulf Coast to the New York City area is reduced by a factor of almost 3 for an increase in deadweight tonnage from 16,000 to 100,000.

a) Pipelines

Pipelines are by far the most extensive method of transporting crude oil, petroleum products, natural gas and LPG. The total mileage of pipelines for the various products is tabulated in Table 12.

TABLE 11

PETROLEUM PRODUCTS TRANSPORTED IN UNITED STATES

	Percentage of Product	
Mode of Transportation	Domestic Crude*	Refined Products†
Pipelines	82.33	30.92
Tankers and Barges	16.25	26.14
Rail Tank Cars	1.42	2.46
Trucks		40.48

* Based on 1969 refinery receipts. Source: U.S. Bureau of Mines, "Crude Petroleum, Petroleum Products, and Natural Gas Liquids, 1969," *Mineral Industry Surveys* (Annual Petroleum Statement, December 15, 1970).

† Source: Association of Oil Pipe Lines, "Shifts in Petroleum Transportation, Table 3," Press Release (April 8, 1971).

About 90 pipeline companies operate common-carrier pipelines in order to accomplish bulk movement of crude oil and products.[201]

The technological development and economical growth of pipelines for transportation of crude oil, gas and liquid products have advanced far since October 7, 1865, when crude oil began to move a distance of 5 miles from Pithole to Miller's Farm, Pennsylvania. This first movement through a 2-inch wrought-iron, lap-welded, threaded and coupled line reduced the transportation cost from $3 to $1 a barrel, and the initial success started a boom in construction of short local lines ranging from 2 to 6 inches in diameter.[202]

In the early 1930's the first long liquid petroleum products pipeline (an 8-inch line, 1,000 miles in length) was engineered and constructed.

The first "big inch" oil line, 24 inches in diameter, was constructed in 1941 to offset wartime tanker losses in the movement of vital crude oil supplies from the Gulf Coast to the Eastern Seaboard.

Liquid petroleum pipelining was advanced substantially further in its maximum of pipe size, length of system and capital outlay, with the completion in 1963 of the 2,600-mile Colonial Pipeline system. This system included 1,046 miles of 36-inch, thin-wall, high-strength line pipe. The outstanding technical success of the Colonial system established adequate proof that the limits on liquid pipeline size will be established by the economics of market demand and horsepower requirements rather than the nature of the product to be transported.

There is no doubt that future problems attendant to the use of higher-strength steels will arise and will be resolved so as to produce safe, serviceable and economical installations.

Perhaps the overriding limitation to progress toward higher-pressure pipelines, liquid or gas, lies in the art and science of metallurgy itself. The steel to meet the strength requirements can be produced now. The safety of both gas and

TABLE 12

PIPELINE MILEAGE FOR CRUDE OIL, PRODUCTS AND NATURAL GAS

Crude Oil*	
Gathering	74,124
Trunklines	70,825
TOTAL OIL (as of Jan. 1, 1968)	144,949
Products Total* (as of Jan. 1, 1968)	64,529
Natural Gas†	
Field and Gathering	64,440
Transmission	233,940
Distribution	554,030
TOTAL GAS (as of Jan. 1, 1969)	852,410
TOTAL (all pipelines)	1,061,888

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* Source: U.S. Bureau of Mines, "Crude-Oil and Product Pipelines, Triennial," *Mineral Industry Surveys* (December 23, 1968). Note: Recent informal estimates indicate no significant change in total oil pipeline mileage as of January 1, 1971, although the distribution is now essentially equal among the three types of pipelines.

† Source: American Gas Association, *1969 Gas Facts* (New York, American Gas Association, Inc., 1969).

liquid pipelines is under the jurisdiction of federal authority. The available steels unfortunately are not immune to environmental deterioration, either from the product within or the soil outside, and therefore must be protected.

Since World War II, a number of industry-inspired and -developed specifications and recommended practices governing pipeline construction have come into being in the liquid petroleum pipeline field. These documents have as their goal the sharing of information designed to ensure that pipelines are installed in accordance with sage and sound engineering practices. Such documents as API Bulletin 1105, "Construction Practices for Oil and Products Pipelines," have been given official industry-wide recognition by virtue of their inclusion in the revised ANSI B31.4 code, Liquid Petroleum Transportation Piping Systems. Code inclusion is the selected route for adoption by the industry of valid new engineering advances.

Welding techniques for the joining of line pipe have kept pace with the metallurgical problems introduced by the development of higher-strength steels and thinner-walled tubes. Again, industry-developed recommended practices such as API Standard 1104, Standard for Welding Pipe Lines and Related Facilities, have been formulated in pace with newly developed techniques and are now absorbed into the ANSI B31.4 code. Welding--whether by gas metal-arc, gas tungsten-arc or shielded metal-arc; whether by manual, semiautomatic or automatic welding techniques--is adequately controlled by the complex welder and welding procedure qualification tests of the API and ANSI standards and codes.

The ANSI B31.4 code was restricted in scope to the design of a pipeline. To meet the needs of the pipeline industry, the code has been expanded to provide guidance in the safe design, construction, maintenance and operation of liquid petroleum pipelines.

Practically all features of the construction of a modern, liquid-petroleum pipeline system--from ditching, stringing, bending and welding to nondestructive testing of the welds, coating inspection, lowering-in and backfilling--are covered in detail in Chapter V of the revised ANSI B31.4 code.

When service deterioration of liquid petroleum pipelines became economically painful to the owners, attention was directed to alleviation of the problem. It became the practice to add wall thickness to pipelines to provide longer service life in the face of environmental deterioration. As pipe sizes and operating pressures gradually increased, the economic advantages of this form of "compensating" for corrosion loss had to yield to the cost for pipe.

The petroleum transportation industry, without governmental intervention, developed and is making extensive use of coatings and supplemental cathodic protection. These modern forms of corrosion mitigation have reached the point where the use of a corrosion allowance is now outmoded in the petroleum-pipeline industry. This fact has been recognized in the latest revision of the ANSI B31.4 code.

Protection against external corrosion has become commonplace, even in mildly corrosive soils, wherever the owners of a pipeline plan for other than a limited operational life for the installation.

External coatings, more and more frequently combined with supplemental cathodic protection, have improved to the extent that a properly applied coating along with a properly engineered supplemental cathodic protection system will result in unlimited life for a pipeline, from the standpoint of external corrosion.

When, or if, internal corrosion in a liquid petroleum pipeline is anticipated, the modern pipeline design engineer considers internal corrosion mitigation as mandatory. He cannot afford to buy added wall thickness to be sacrificed to internal corrosion. He makes a choice between product conditioning through dehydrating or sweetening, and the creation of a corrosion barrier by means of inhibition or internal coating of the line.

In the petroleum industry, the term "oil pipelines" has come to mean both crude and products lines whether the products are finished or only partially processed. The hardware (pipe, valving, pumping equipment, etc.) is essentially the same for both services. However, there are some differences in both equipment and methods of operation. Generally, crude lines are of larger diameter than products lines.* The capacity or pumping rate of products lines is only slightly affected by changes in the temperature, and resulting change in viscosity, of the pumpage. In crude-oil lines, temperature of the pumpage has considerable effect, depending upon the nature of the oil being pumped.

Crude pipelines, except in the case of some sour and corrosive oils, are not subject to internal corrosion. Products lines, however, need internal protection. To protect the interior of pipe in products service, either the pumpage is dehydrated or corrosion inhibitors are added. In the case of interior corrosion of steel tanks, the opposite is true. Tanks in product service rarely show serious internal corrosion. On the other hand, internal corrosion in crude-oil tankage remains a somewhat serious, expensive problem. The attack

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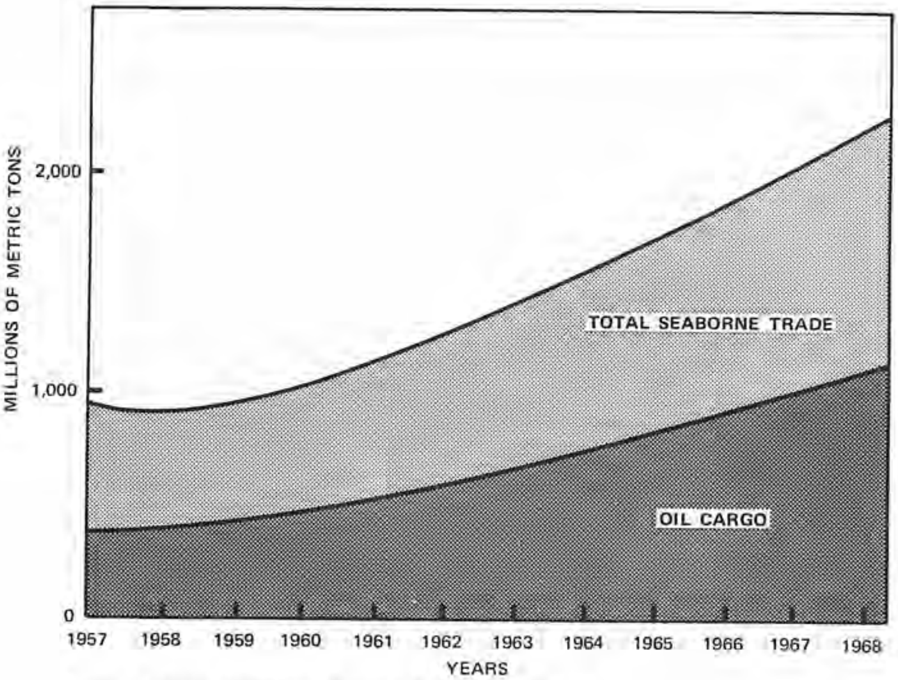
*Notable exception is the huge Colonial Pipeline system.

is usually most severe in bottoms, because of saline bottom water, and the upper rings and roof, because of constant exposure to vapors containing various amounts of sulfur. Cone roofs are, of course, more subject to attack than floating roofs.

A products line adequately protected against internal corrosion rarely needs internal scraping or "pigging." On the other hand, most crude lines need regular scraping to remove paraffin buildup on the inside wall. This paraffin coating probably accounts for the lesser interior corrosion in crude-oil lines. Mobile modes of transportation are used for products as well as pipelines.

b) Tankers

Marine tankers play dual and vital roles. They account for over half of the commerce on the high seas (see Figure 9) and provide, today, the only means of transporting petroleum in bulk from overseas. They are also next in importance to pipelines for domestic movement of crude oil and its related products.



Source: Statistics published by Statistical Office, United Nations.

Figure 9. Petroleum's Share of Seaborne Trade.

The tonnage and number of ships in the United States and world tanker fleets are given in Table 13.

Although the increase in individual tanker size is spectacular, the effect of the average size of all vessels in service has been relatively small. New tankers are to be built over 400,000 deadweight tons (DWT), but the average size at the end of 1969 internationally was 37,500 DWT (see Table 13). By the end of 1970 this average had risen to 41,800 DWT.

Marine tankers have also been developed for the transportation of LNG. Two classes of tanks are used: self-supporting tanks and membrane tanks. Self-supporting tanks are independent of the ship's hull and rest inside the hold. Membrane tanks use the ship's hull as the cargo tank; insulation is attached to the hull and a thin membrane is provided to keep the LNG from permeating the insulation.

TABLE 13

SIZE AND TONNAGE OF MARINE TANKER FLEETS
(Oceangoing Vessels of 2,000 Gross Tons and Over)

	Number of Ships	Total DWT	Average DWT
U.S. Fleet			
Present	365	8,797,900	24,100
Ordered*	22	1,458,000	66,300
World Fleet			
Present	3,893	146,029,100	37,500
Ordered*	570	59,328,000	104,100

* On order or under construction as of December 31, 1969.

Source: *Analysis of World Tank Ship Fleet, December 31, 1969* (Philadelphia, Sun Oil Company, Corporate Development Group, August 1970).

Presumably the 300,000-DWT tankers now in use would show an even lower unit cost, although they are not being used in coastwise shipping.

Only a few harbor facilities exist to handle these giant tankers. Harbor depths are not the only problem. Horizontal clearances at bridge locations on channels leading to many major ports will not tolerate the broad-beamed giants, and U.S. coast channels must be significantly deepened to accommodate the big tankers. However, joint offshore terminal and pipeline facilities on the U.S. East Coast capable of handling the giant tankers coming into world oil trade are being investigated.

One solution for loading and unloading the new giant tankers is the offshore buoy connected by submarine pipeline to shore facilities. A type in general use at many Far Eastern terminals is sketched in Figure 10.

c) Barges, Rail Tank Cars, Trucks

Table 14 compares the number of units and total capacity of mobile means of transporting oil inland and in shallower waters.

The barge is the most economical means of transporting crude oil and petroleum products in the United States. Barge units navigate approximately 25,000 miles of inland waterways. The average towboat with 3,200 to 4,300 horsepower (HP) can push barges of 15,000 to 25,000 tons, while larger towboats with about 9,000 HP can handle barges up to 50,000 tons. An increase in upstream speeds so that 5 to 8 miles per hour can now be reached with maximum loads has contributed to the economy of this transportation means and increased the annual capacity.

The general theme of improvements in barge technology has been the application of the most advanced engineering developments to reduce the unit cost of transportation. This has been achieved by increasing the speed and size of the tows

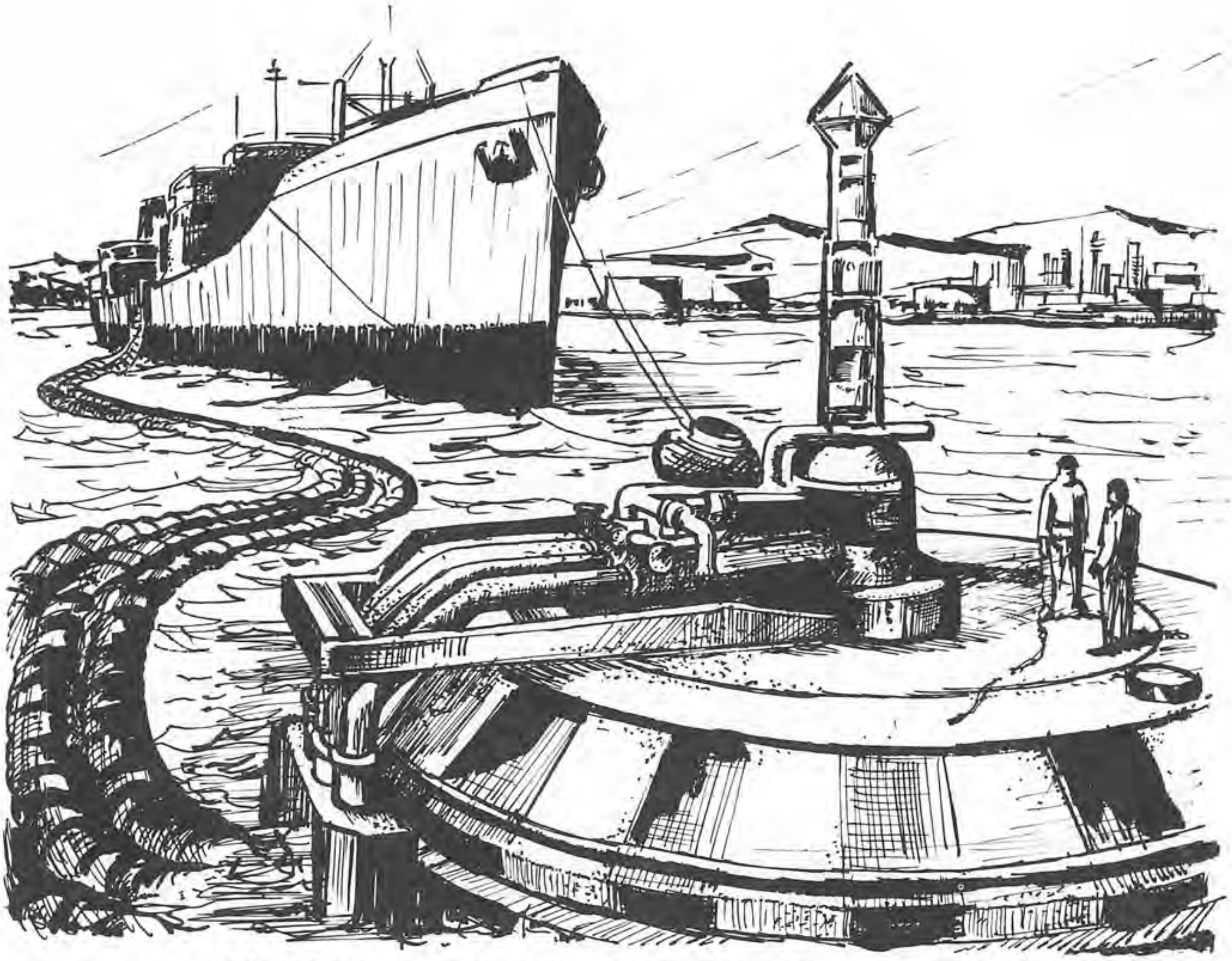


Figure 10. Terminal Facilities for Giant Tankers.

TABLE 14

U.S. OIL TRANSPORTATION CAPACITIES

Mode of Transportation	Number of Units	Total Capacity (In 1,000 Bbls.)
Barges (Petroleum)	2,925	35,509
Tank Trucks & Trailers	81,300	11,840
Rail Tank Cars	185,228	50,631

Source: NPC, *U.S. Petroleum and Gas Transportation Capacities* (1967).

and decreasing the manpower required to operate them by providing mechanical and electrical devices to assist the men. Great effort is being expended to maximize the percentage of the time that the barges are moving loaded. This increased utilization has been important in keeping barge transportation costs low.

The trend toward increased utilization and toward development of specialized barges is expected to continue.

Just as the equipment has improved, so have the waterways over which the barge traffic moves. Continuous improvements in channel conditions and extensions of the navigable waterway system have been made. A notable project is the simplification and expansion of the locks and dams on the Ohio River system, one of the busiest of our waterways. The system in being at the end of World War II consisted of 46 low-lift dams, each with a single 600-foot lock. It is being replaced by a system of 19 high-lift dams each with dual locks, one 1,200 feet long, the other 600 feet long. The smaller number and larger size of the locks reduce the voyage times, thereby decreasing the cost of barge transportation.

Tank trucks and drawn tank trailers have increased in capacities up to 10,000 gallons. Regulations covering vehicle size, weight and operating speeds have significantly influenced the design of the new trucks and trailers, and technological advances in equipment have increased their reliability and lowered maintenance costs.

Safety has been constantly improved in the development of truck delivery equipment. Suspensions and tank design have improved stability. Brakes, tires and power steering have been improved for greater safety and reliability in the operation of the vehicle.

Improved efficiency has been accomplished by designing faster loading and unloading systems. Large-size piping, high-capacity vents, quick-connect hose couplings, and more efficient internal valves and unloading valves have resulted in deliveries up to 600 gallons per minute on gravity unloading systems. Submerged loading and bottom loading have resulted in greater safety and vehicle utilization.

Aviation fueler designs have changed even more radically than the delivery equipment. In the late 1940's, fuelers were used for servicing gasoline-powered propeller aircraft at rates up to 200 gallons per minute. The advent of jet aircraft radically changed fueling requirements. Pumping rates had to be increased. Other considerations in the design were fuel cleanliness, pressure regulation to prevent damage to aircraft tanks, fuel handling safety, maximum flexibility, and safety in servicing the aircraft.

Railway tank cars are still an important mode of transportation, even though the volume of petroleum products moved by rail has diminished in recent years. The capacity of individual tank cars has increased to approximately 30,000 gallons, and technology has improved the construction costs, thus helping to lower the cost per unit moved.

The tank car fleet maintains an importance in the overall transportation scheme because the cars are ideally suited to movement of special, limited-volume products from various origins to diverse destinations.

Gasoline and distillates formerly moved in 8,000- to 10,000-gallon capacity cars and now move in many instances in cars of capacities between 20,000 and 30,000 gallons. Practical liquefied-gas car capacities have been stepped up from around 11,000 gallons to 30,000 to 33,000 gallons. A 50,000-gallon car has found limited use in this latter category.

The ability of tank cars to handle specialized cargoes has been greatly improved, and it is expected that the trend to specialized tank cars will continue.

The particular utility to the petroleum industry of rail tank cars is an advantage that is shared in many ways with tank trucks.

3. Marketing

While marketing systems exist for all petroleum products, the system for automotive gasoline is used here to illustrate the scope of the industry's marketing operations for two reasons: It is by far the most extensive, and it provides outlets for the industry's principal product.

Automotive gasoline is generally directed from a refinery or terminal to (1) service stations, (2) individual, large-volume "consumer" accounts, or (3) small bulk plants which in turn normally direct it to service stations or consumer accounts. A 1962 Los Angeles study indicated that 95 percent of automotive gasoline was marketed through service stations and 5 percent through consumer accounts.[203] Statistical information is not available on the total number of gasoline terminals and bulk plants in the United States. A rough estimate would be 20,000. There were 219,000 service stations in the United States in 1968. While the total consumption of automotive gasoline is expected to increase, recent industry trends indicate that the number of service stations will decrease. Thus the average station will handle a larger volume of sales.

Section 2.
THE MANAGEMENT OF CHANGE--A BALANCING OF PRIORITIES

The remainder of this chapter will review some of the major factors which must be taken into consideration by management--in government or the petroleum industry--before it decides on any course of action involving environmental conservation.

A. Control of Water and Land Pollution

Regard for the protection of both land and water from harmful spillages of petroleum liquids is essential in all petroleum industry operations. However, the circumstances that dictate the cost-effectiveness of preventive measures may vary considerably from one operation to another.

In exploring, refining, pipelining and marketing, the major problems are preventing small spills and containing them when they occur. Only in drilling and production and in the transportation of petroleum liquids by tanker or barge does the problem of large spills arise. Here the problems are to keep the number of such spills to a minimum and to be prepared to prevent damaging pollution when they do happen.

In any case, the proper control measures must be chosen to satisfy society's needs for safety, environmental conservation and an uninterrupted supply of energy fuels.

1. Production

Determining cost-effectiveness in production operations requires balancing requirements for low-cost basic energy against the increasingly difficult conditions under which petroleum must be found and produced.

The problem is compounded because it is almost impossible to determine the true cost of finding and developing a barrel of crude oil at any given time. Much depends on the amount of oil in the reservoir. Estimates of total recoverable oil made soon after discovery may not be accurate.

It has been established, however, that new technology in drilling and production has resulted in substantial cost savings. So has wider well spacing. However, based on analyses of cost reduction from new technology and related practices in drilling, production, corrosion control and well spacing, an NPC report indicated that had 1950 practices been applied in 1965 to perform the same drilling and production operations, the estimated cost per barrel of oil produced would have been the equivalent of $0.76 per barrel higher (i.e., drilling--$0.35; production--$0.32; corrosion control--$0.09). In addition, the elimination of unnecessary drilling in 1965 through the use of wider well spacing practices provided estimated cost savings ranging from $0.175 to $0.35 per barrel of oil produced. It has been estimated that without developments in these two areas from 1950 to 1965, the cost of crude oil would be at least $1.00 higher per barrel produced.[204]

At the same time, the search for oil and gas has extended more and more into offshore regions, where expenses are substantially higher than for comparable onshore operations. Total exploration and development costs are expected to increase still more as water depths increase, with costs in 1,000 feet of water from three to five times those in 100 feet.[205]

It was also deemed possible to obtain an indication of projected changes in total exploration and production costs with water depth by analysis of the effects of water depth on historical costs of exploration drilling, development drilling, production facilities and pipelines. As shown in Table 15, these components of the total exploration and development costs were expected to be about twice as costly in 600 feet (183 meters) of water, and three to five times as costly in 1,000 feet (305 meters) of water, as they are in 100 feet (30 meters) of water.

TABLE 15

VARIATION OF MAJOR COMPONENTS OF EXPLORATION AND DEVELOPMENT COST WITH WATER DEPTH

	Cost Multiplying Factor		
Cost Component	Base Case 100 ft.	600 ft.	1,000 ft.
Exploration Drilling*	1.0	1.5 - 2.0	2.0
Development Drilling	1.0†	2.0 - 2.5†	2.5 - 3.0‡
Production Facilities	1.0§	1.0 - 1.5§	3.0 - 8.0‖
Pipelines#	1.0	1.0 - 2.0	2.0 - 3.0

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* Drilling is done from mobile or floating rigs.

† Utilizing and including the cost of fixed piling platforms.

‡ Drilled from floating rig and completed utilizing underwater wellhead. Also includes cost of flowline to a production facility.

§ Cost of facilities required to process, measure and store crude oil on existing fixed piling platform.

‖ Cost of facilities and floating or underwater foundation required to process, measure and store crude oil.

Cost per mile.

The NPC report *Impact of New Technology on the U.S. Petroleum Industry 1946-1965* pointed out that it must be remembered that the specific costs and capabilities may vary widely. In Cook Inlet, Alaska, for example, due to tides and ice floes, the cost of a platform in 100 feet (30 meters) of water is $8 million to $15 million compared to $1 million to $2 million in the Gulf of Mexico, and the cost of an 8-inch pipeline is $60 per foot compared to $10 per foot in the Gulf.[206]

The effects of costs savings per barrel of oil because of technological improvements on the one hand and the projections of increasingly difficult operating conditions on the other must be balanced by the manager with a third factor, the costs and benefits of environmental conservation. The close interrelationship of all of the technical problems and technical solutions to these three factors are described in some detail in the next chapter, "Exploration and Production."

2. Refinery Operations

The petroleum industry embarked a good many years ago on an extensive program to control pollution from refinery operations and has sought, both through industry association efforts and cooperation with government, to disseminate information which would be of general assistance to the industry and to the public in taking cost-effective action on similar control problems.

The API Committee on Disposal of Refinery Wastes, formed in 1929 and comprised of engineers and scientists, collects information which assists refiners in preventing noxious wastes from leaving refinery areas. Its areas of concern are in the fields of chemical, civil and sanitary engineering, as well as in analytical chemistry and biology.

The committee is responsible for the development of a technical publication entitled *API Manual on Disposal of Refinery Wastes* (the first volume appeared in 1935). The manual reflects in detail the state of conservation technology in oil refining. Two of its volumes deal with water pollution control, two with air pollution control and one with solid wastes disposal. (Exact titles are given on p. 38.) The manual covers all known sources of potential contamination, and its suggested treatment methods are systematically revised as industry research provides new information on which to base effective action.

The manual outlines the treatment processes proved successful in actual practice, and individual refiners are able to adapt these processes when necessary to fit their own particular situations. Although following the manual's recommendations is voluntary on the part of any refiner, the methods it outlines and the equipment it describes form the basis of the pollution-abatement programs of virtually all U.S. refineries.

In a cooperative program involving government and industry, the Federal Water Pollution Control Administration (now EPA) and the American Petroleum Institute initiated in 1968 a joint research project, with objectives of:

- Determining the tolerance of municipal and industrial waste-treatment systems to various hydrocarbon compounds
- As a basis for effecting this improvement, determining the fate of oil in existing biological oxidation systems as well as the tolerance of these systems
- Examining technical and economic feasibility of pre-treatment in conjunction with municipal and industrial biological treatment systems.

A series of laboratory studies have been conducted in bench-scale equipment to accomplish the project objectives outlined above. In these studies, hydrocarbons of various types and concentrations have been used.

The investigation during this period was principally concerned with the effects of the different oil compounds on aerobic continuous-flow reactors. Respirometer studies were also performed on oil compounds and simple benzene derivatives. Presently, studies are under way to examine the effect of low concentrations of oil on continuous systems. Investigations are also under way to determine the possible improvement of pretreating the oil before it is carried into a biological system.

Future studies will include: (1) acclimation of the mixed heterogeneous bacterial population to oil compounds such as crankcase oil, crude oil, vegetable oil and the settled emulsified oil compound; (2) investigation of the recovery of the aerobic biological units to shock oil loads; (3) respirometer studies on the oil compounds, with principal emphasis on monitoring the degradation of individual compounds by the microbial mass; and (4) anaerobic study to examine the ability of strict anaerobes to degrade these oil compounds.

A task force consisting of industry and government representatives is assigned to this project to consult with the contractor on the program.

Information on the costs of pollution control, both municipal and industrial, is important if consideration is to be given to cost-benefit relationships in establishing goals and priorities in programs to protect and improve the quality of our water resources. The Federal Water Pollution Control Administration was required under the amended Federal Water Pollution Control Act to prepare "Industrial Waste Profiles" for 10 industries, including petroleum refining, to provide information on costs and alternatives involved in dealing with the industrial waste problem. The American Petroleum Institute, recognizing the need for up-to-date petroleum industry data, has conducted periodic surveys of petroleum industry expenditures for various phases of air and water conservation. These studies, discussed below, are probably the most comprehensive available.

API Expenditures Report. The report, *Air and Water Conservation Expenditures of the Petroleum Industry in the United States*, was first published in 1968 and then brought up-to-date in 1971. Only portions related to water are discussed here.

It is very difficult in many cases to determine what portion of the cost of installing and operating a particular facility should be allocated to waste-water control, air pollution control, processing, etc., because some projects have multiple benefits and because many costs for pollution are never broken out of design and construction totals. Arbitrary guidelines to put the entire industry on as much the same reporting basis as possible were established. The guidelines used in the API expenditures report for reporting water conservation expenditures as a percentage of total cost are listed on p. 88.

Table 16 summarizes total petroleum industry expenditures for water conservation as well as figures for the refining segment of the industry. Capital spending for water pollution control has increased fivefold from $15.4 million in 1966 to an estimated $76.9 million in 1970. Pending legislation could, however, drastically increase this already rapid rate of growth.

FWPCA Report. The Federal Water Pollution Control Administration report, *Cost of Clean Water--Volume III, Industrial Waste Profile No. 5, Petroleum Refining*, is a detailed report covering fundamental manufacturing processes, water use and reuse, waste quantities and characteristics, waste reduction practices and their effectiveness, and waste treatment costs with projections and estimates to 1977. Much of it covers the same ground discussed in Chapter Five Five, entitled "Refining." Only that portion dealing with costs is discussed here. In contrast to the API survey which attempted to deal with annual spending on an industry-wide basis, the FWPCA study attempts to develop overall refining industry waste-water facilities replacement costs and annual operating costs. In addition, waste treatment costs for an individual hypothetical refinery are estimated.

GUIDELINES

For purposes of uniformity in reporting of expenditures, it is requested the examples listed below be considered in determining the expenditures of capital and research and development. The recommended total expenditures to be credited to water conservation costs have also been indicated. It may be desirable to supplement this listing of examples in those cases where additional items are found applicable. It is emphasized these are guidelines to be used only in those cases where the actual costs are not available.

I CAPITAL ITEMS

	% of Total Cost To Be Used
A. Production	
1. Deep Well Disposal	100
2. Other Oil Loss Control (Offshore, Land, etc.)	100
3. Tank Bottom Disposal and Treatment	100
4. Surface Casing on Wells (1)	100
5. Saltwater Disposal (2)	100
6. Air Flotation, Air Cooling	100
7. Cooling Towers	100
8. Sanitary Sewerage Systems	100
B. Transportation	
1. Oil Recovery from Ballast and Working Operations at Sea	100
2. Ballast and Bilge Water Shore Treatment Facilities	100
3. Oil Spill Booms	100
4. Other Facilities and Materials to Control Oil Spills	100
C. Marketing	
1. Waste Oil Recovery	100
2. Oil Recovering at Bulk Terminals	100
D. Manufacturing	
1. Sour H_2O Strippers and/or Oxidizers	100
2. Desalter--H_2O Strippers	100
3. Flocculators and Clarifiers	100
4. Oil Recovery and Handling Systems	100
5. Oxidation Ponds and Mechanical Aerators	100
6. Activated Sludge Plants	100
7. Trickling Filter Plants	100
8. Air Flotation	100
9. Pumpout Systems	50
10. Mechanical Seals and Pumps	10
11. Regeneration Caustic Systems	50
12. Spent Caustic Treating Systems	100
13. Sludge Incinerators	100
14. Collection Systems--Separate Sewers, etc.	100
15. Air Cooling	25
16. Cooling Towers	50
17. Sanitary Sewerage Systems	100

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(1) Incremental installation costs solely for purpose of protecting freshwater formation.

(2) Does not include cost of pressure maintenance or secondary recovery operations.

TABLE 16

PETROLEUM INDUSTRY EXPENDITURES ON WATER CONSERVATION
(Thousands of Dollars)

Total for Production, Transportation, Marketing and Manufacturing*	1966	1967	1968	1969	1970 (est.)
Capital	79,016	113,728	127,595	136,518	184,753
Operating and Maintenance	45,797	53,246	58,816	66,030	77,316
Administrative	11,476	13,299	15,862	18,167	21,259
Research and Development	9,429	10,543	2,897	3,430	4,980
TOTAL	145,718	190,816	205,170	224,145	288,308
Refining alone					
Capital	15,368	30,544	39,334	49,075	76,857
Operating and Maintenance	13,661	15,932	19,701	22,790	26,910
Administrative†	3,655	3,912	6,136	7,797	8,961

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* Includes refining, chemical plants and other.

† Estimated from total manufacturing administrative expenditures based on ratio of refinery capital expenditures to total manufacturing capital expenditures.

Source: American Petroleum Institute, *Report on Air and Water Conservation Expenditures of the Petroleum Industry in the United States, 1966-1970,* Publication No. 4075 (Washington, D.C., February 1971).

Using industry survey data from 1959 and extrapolating the data to cover the entire industry, assuming planned additions were made and injecting a factor for increased construction costs, 1966 refinery waste-water facilities replacement value was pegged at $275 million. Related operating costs were estimated at $55 million.

Estimated individual refinery waste treatment costs were developed through a procedure based on the premise that waste loads can be determined for, or assigned to, individual refining processes. Many in the petroleum refining industry believe this to be an unwarranted premise because so many variable factors come into play. In addition, the amount of actual data available was rather limited. But if the premise can be accepted, the procedures using the data were logical in their sequence. Consideration was given to refineries of varying sizes employing technology of varying age or stage of development.

Waste-water flows and principal pollutant loadings for small, medium and large refineries of older, typical and newer technologies were estimated (see Table 17). Capital (1967 construction costs) and annual costs of waste treatment processes required to handle these wastes adequately on an end-of-pipe basis were estimated as shown in Tables 18, 19 and 20 for plants employing older, typical and newer technology.

TABLE 17

POLLUTIONAL LOADS FROM REFINERIES OF VARIOUS TECHNOLOGIES AND SIZES

Technology	Size	Throughput (bpsd)	Flow (mgd)	BOD (lbs/day)	Phenol (lbs/day)	Sulfide (lbs/day)
Older*						
	Small	30,000	7.5	12,000	900	300
	Medium	75,000	18.7	30,000	2,250	750
	Large	150,000	37.5	60,000	4,500	1,500
Typical†						
	Small	30,000	3.0	3,000	300	90
	Medium	75,000	7.5	7,500	750	225
	Large	150,000	15.0	15,000	1,500	450
Newer‡						
	Small	30,000	1.5	1,500	300	90
	Medium	75,000	3.8	3,250	750	225
	Large	150,000	7.5	7,500	1,500	450

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* Older--using relatively inefficient or obsolete refining processes.

† Typical--using those processes most widely used today.

‡ Newer--using all or most of the advanced processes.

Source: *The Cost of Clean Water--Vol. III, Industrial Waste Profile No. 5, Petroleum Refining,* FWPCA Publication No. I.W.P.-5 (1967).

TABLE 18

WASTE TREATMENT OR REMOVAL COST INFORMATION*--OLDER TECHNOLOGY

		Small Refinery		Medium Refinery		Large Refinery	
Waste Treatment Process	Economic Life (Years)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)
API Separator (Flow)	30	105,000	23,000	261,800	36,000	525,000	55,000
Earthen Separators with Skimming	100	9,500	17,500	23,500	24,250	47,000	27,000
Air Flotation (Flow)	20	222,750	37,000	553,250	74,000	995,000	117,750
Activated Sludge	30	655,000	120,000	1,425,000	187,000	2,850,000	375,000
Aerated Lagoon	30	110,000	24,500	240,000	51,500	480,000	103,000
Trickling Filters BOD	30	1,512,000	80,000	3,300,000	163,750	6,600,000	328,250
Oxidation Pond	100	120,000	4,000	252,000	4,000	528,000	7,500
Evaporation Pond (Without Dredging)	20	90,000	900	150,000	1,500	281,250	2,800
Thickening and Vacuum Filtration (Sludge)	20	120,500	22,000	150,000	50,000	265,000	58,750
Incineration (Sludge)	30	168,000	43,000	375,000	74,200	735,000	116,000
Slop Oil Treatment	50	114,000	11,000	281,500		563,000	
Sour Water Stripping	20	154,000		325,000		655,000	

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* End-of-pipe treatment.

Source: *The Cost of Clean Water--Vol. III, Industrial Waste Profile No. 5, Petroleum Refining,* FWPCA Publication No. I.W.P.-5 (1967).

TABLE 19

WASTE REDUCTION OR REMOVAL COST INFORMATION*--TYPICAL TECHNOLOGY

Waste Treatment Process	Economic Life (Years)	Small Refinery		Medium Refinery		Large Refinery	
		Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)
API Separator	30	46,500	12,500	105,000	22,000	210,000	33,000
Earthen Separators with Skimming	100	4,000	11,000	9,500	17,500	19,000	24,000
Air Flotation	20	111,500	18,500	222,750	37,000	371,250	55,500
Activated Sludge (95% Overall)	30	235,250	91,500	472,150	98,000	767,000	150,000
Aerated Lagoon (80%)	30	36,000	18,750	72,000	24,500	132,000	41,250
Trickling Filters (80%)	30	450,000	80,000	1,020,000	84,000	1,800,000	160,000
Oxidation Pond (80%)	100	38,500	4,000	81,000	4,000	141,000	7,500
Evaporation Pond	20	56,250	575	90,000	900	127,500	1,275
Thickening and Vacuum Filtration (Sludge)	20	59,000	11,500	82,500	20,500	108,500	22,500
Incineration (Sludge)	30	187,000	19,000	198,000	32,200	202,000	49,000
Slop Oil Treatment	50	146,000		114,000	11,000	227,000	
Sour Water Stripping	20	63,000		154,000	15,000	263,000	

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* End-of-pipe treatment.

Source: *The Cost of Clean Water--Vol. III, Industrial Waste Profile No. 5, Petroleum Refining,* FWPCA Publication No. I.W.P.-5 (1967).

TABLE 20

WASTE REDUCTION OR REMOVAL COST INFORMATION*--NEWER TECHNOLOGY

		Small Refinery		Medium Refinery		Large Refinery	
Waste Treatment Process	Economic Life (Years)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)	Capital Costs (Dollars)	Annual Operating & Maintenance Costs (Dollars)
API Separator	30	30,000	11,000	53,200	13,000	105,000	23,000
Earthen Separators with Skimming	100	3,750	11,000	5,000	11,500	9,500	17,500
Air Flotation	20	70,000	14,500	181,500	25,500	222,750	37,000
Activated Sludge	30	125,750	67,000	251,000	91,000	472,000	98,000
Aerated Lagoon	30	20,000	15,000	36,500	20,000	72,000	24,500
Trickling Filters	30	255,000	56,250	487,500	80,000	1,020,000	85,000
Oxidation Pond	100	20,000	3,000	40,300	4,000	82,500	4,000
Evaporation Pond	20	40,000	500	66,500	700	90,000	900
Thickening and Vacuum Filtration (Sludge)	20	35,000	9,500	62,500	12,000	82,500	20,500
Incineration (Sludge)	30	121,000	14,400	195,600	19,700	195,000	32,000
Slop Oil Treatment	50	22,500		57,000		114,000	
Sour Water Stripping	20	39,500		80,000		154,000	

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* End-of-pipe treatment.

Source: *The Cost of Clean Water--Vol. III, Industrial Waste Profile No. 5, Petroleum Refining,* FWPCA Publication No. I.W.P.-5 (1967).

Table 21 gives estimated waste loading from individual processes. From these data the capital and annual operating costs (1967 basis) of waste-water facilities for a hypothetical 100,000-barrel-per-stream-day refinery using typical technology at three different levels of treatment were estimated. The results are as follows:

	Degree of Treatment*		
	Low	Intermediate	High
Capital Cost	$219,000	$445,000	$1,126,000
Annual Operating & Maintenance Cost	33,000	72,500	187,000

It should be emphasized that these estimates are not well substantiated by refinery experience and are viewed as being too low by many industry experts. The ratios of costs for low, intermediate and high degrees of treatment may be more realistic.

To supplement this type of summary analysis, it may be useful to provide illustrations of the balancing factors which must be taken into account in order to arrive at a course of action which will provide a properly cost-effective solution.

For example, selection of a particular type of biological treatment for a particular refinery can involve many factors. The economics of construction and operations are primary factors, but effluent quality often dictates process selection. The conventional trickling filter may be used where there is ample land, where effluent requirements do not demand a highly purified effluent, and where capital cost is of less concern than operating cost. On the other hand, the activated-sludge process has lower capital cost, takes less space and can produce a higher-quality effluent, but has higher operating costs. Oxidation ponds are used only where land is plentiful and where capital and operating costs must be low.

Many types of cost-benefit judgments related to the need for or feasibility of a treatment method must be taken into account as, for example, the status of existing plant systems and options to dispose of wastes. Sewer systems in older refineries are usually not segregated according to type of waste, and the costs of converting to a separated system are usually prohibitive. Upgrading effluent treatment at old refineries is very costly, largely because of difficulty in revamping sewer systems.

Disposal by sale of spent chemicals from refinery operations is frequently the most attractive disposal method. It is sometimes profitable, but may be attractive even if it entails a loss. Sale usually requires segregation of spe-

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*Low..........Includes API separator plus slop-oil treatment.

Intermediate..Includes API separator, slop-oil treatment, aerated lagoon and foul-water stripper.

High.........Includes API separator, slop-oil treatment, foul-water stripper, activated sludge, thickening, vacuum filtration and incineration.

Source: U.S. Department of the Interior, Federal Water Pollution Control Administration, *The Cost of Clean Water, Vol. III, Industrial Waste Profile No. 5, Petroleum Refining* (Washington, D.C., November 1967), Table 18.

TABLE 21

WASTE LOADINGS AND VOLUMES PER UNIT OF FUNDAMENTAL PROCESS THROUGHPUT IN OLDER, TYPICAL AND NEWER TECHNOLOGIES

Fundamental Process	Older Technology				Typical Technology				Newer Technology			
	Flow gal/bbl	BOD lbs/bbl	Phenol lbs/bbl	Sulfides lbs/bbl	Flow gal/bbl	BOD lbs/bbl	Phenol lbs/bbl	Sulfides lbs/bbl	Flow gal/bbl	BOD lbs/bbl	Phenol lbs/bbl	Sulfides lbs/bbl
Crude Oil and Product Storage	4	0.001	*	*	4	0.001	*	*	4	0.001	*	*
Crude Desalting	2	0.002	0.20	0.002	2	0.002	0.10	0.002	2	0.002	0.05	0.002
Crude Fractionation	100	0.020	3.00	0.001	50	0.0002	1.00	0.001	10	0.0002	1.00	0.001
Thermal Cracking	66	0.001	7.00	0.002	2	0.001	0.20	0.001	1.5	0.001	0.20	0.001
Catalytic Cracking	85	0.062	50.00	0.030	30	0.010	20.00	0.003	5	0.010	5.00	0.003
Hydrocracking	not in this technology				not in this technology				5	*	*	*
Reforming	9	t†	0.70	t	6	t	0.70	0.001	6	t	0.70	0.001
Polymerization	300	0.003	1.40	0.220	140	0.003	0.40	0.010	not in this technology			
Alkylation	173	0.001	0.10	0.005	60	0.001	0.10	0.010	20	0.001	0.10	0.020
Isomerization	not in this technology				not in this technology				*	*	*	*
Solvent Refining	8	*	3.00	t	8	*	3.00	t	8	*	3.00	t
Dewaxing	247	0.520	2.00	t	23	0.500	1.50	t	20	0.250	1.50	t
Hydrotreating	1	0.002	0.60	0.007	1	0.002	0.01	0.002	8	0.002	0.01	0.002
Deasphalting	*	*	*	*	*	*	*	*	*	*	*	*
Drying and Sweetening	100	0.100	10.00	*	40	0.050	10.00	*	40	0.050	10.00	*
Wax Finishing	*	*	*	*	*	*	*	*	*	*	*	*
Grease Manufacture	*	*	*	*	*	*	*	*	*	*	*	*
Lube Oil Finishing	*	*	*	*	*	*	*	*	*	*	*	*
Hydrogen Manufacture	not in this technology				not in this technology				*	*	*	*
Blending and Packaging	*	*	*	*	*	*	*	*	*	*	*	*

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* Data not available for reasonable estimate.

† t = Trace.

Source: *The Cost of Clean Water--Vol. III, Industrial Waste Profile No. 5, Petroleum Refining,* FWPCA Publication No. I.W.P.-5 (1967).

cial streams and may require changes in operating procedures and equipment and concentration of waste materials to make utilization more profitable to the buyer and shipping less costly.

There can be no doubt that tightened pollution control efforts have had, and will continue to have, a major impact on industry-wide refinery capital spending plans and operating costs. The magnitude of the effort can perhaps best be judged by recent historical survey data. However, while such data are useful and perhaps represent a lower limit on spending for the near future, they are not, in themselves, adequate for forecasting. A more important basis will be estimates of what may be required in capital investment and operating costs for individual plants--including refineries--in individual river basins or stream stretches.

Now that receiving-water quality criteria have been established for most waters of the country, these costs can be estimated, but only after the following steps have been taken:

- Determining present stream quality
- Assembling present waste loads
- Calculating waste load reduction required, making approximate allowance for growth of population and industry
- Making individual allocations of waste loads, taking into account the age of the plants involved, present degree of treatment, and technology available.

The FWPCA made a commendable effort to provide a systematic basis for estimating costs of refinery waste treatment. The assignment was a difficult one that had to be completed in a minimum amount of time and with a relatively small amount of data. The results should be used with caution.

3. Marketing

The disposal of used crankcase oil and used industrial cutting oils and lubricants is a lesser known but important factor that marketing managers must recognize in determining the cost-effectiveness of environmental control activities.

Re-refining operations, which formerly handled many waste oils, are becoming economically marginal. Consequently, disposal becomes a cost problem for service stations and auto repair shops as well as for larger industries.

Municipal sewage treatment facilities, if up-to-date and properly operated, can handle some oil, but this disposal problem needs further study. Burning appears to be one effective disposal method.

4. Oil-Spill Recovery and Containment

In determining cost-effectiveness, the containment and cleanup of spilled oil is perhaps the most difficult to assess of all environmental conservation activities. Operational costs can usually be measured in terms of expenditures for containment and cleanup action, but the benefits to society from such action are much more difficult to weigh.

The risk of spills is inevitable when society depends so heavily on large volumes of petroleum for its energy. The goal of the industry--already attained to a substantial degree in many operations--is to reduce that risk to its practical minimum.

Top priority is currently being given to the development of equipment and techniques for containing and recovering large-volume spills in the open sea.

B. Control of Atmospheric Pollution

Control of atmospheric pollution is more a problem of the use of petroleum products than of the industry's operations. A detailed discussion on use of products follows later in this report. However, some operational phases--notably refining--do have emissions control problems for which the cost-effectiveness of control measures is a significant management problem.

1. Refineries

The overall cost of adequate air pollution control facilities in a petroleum refinery is a function of many factors including the complexity of the units, types of crude oils processed, location and local regulations. However, most refineries now consider that air pollution control equipment will add at least 5 percent* to the overall cost of construction of new refineries, which is about triple the percentage cost considered adequate in the early 1950's.[207] Furthermore, installing air pollution control equipment on existing or older equipment is likely to cost from 150 to 200 percent of the amount for comparable equipment in new installations. It is considered likely that this percentage will continue to increase as additional technology is developed.

A complete survey of the petroleum refining industry investment for emissions controls has not been completed, but an indication of the magnitude of the potential costs may be estimated from application of the above percentages to appropriate industry statistics. Construction costs of a major complete refinery to produce high yields of distillate and gasoline are currently on the order of $1,700 per barrel per day of capacity; utilizing the above 5-percent factor, the projected cost of air pollution control would be approximately $85 per barrel per day of capacity. Application of this value to the current 13 million barrels per day of U.S. refinery capacity would suggest an investment of at least $1.1 billion for controlling refinery atmospheric emissions to a level consistent with current technology and regulations.

Although the above values represent very large investments, the investment required for prevention of refinery emissions is a small percentage of the total investment. Refinery costs for internal control will be minor compared to the impact of capital expenditures for processing changes which might be required to minimize air pollution from the use of refinery products.

Another indication of the magnitude of the refining industry's investment in air pollution control equipment was reported in an industry-wide survey in 1966.[208] United States refineries reported expenditures exceeding $200 million for the period 1956-1965 and projected through 1966. This represents approximately $20 per barrel per day of capacity. These expenditures were allocated to prevention of various types of emissions, as shown in Table 22.

Overall costs of refinery air pollution control result in net overall reduction in profits; however, some controls such as hydrocarbon and sulfur recovery have an economic return. In the survey mentioned above, refineries reported that 37 percent of the expenditures for control equipment in the 1960-1965 period had a good economic payout when compared to normal investment practices of the company. Thirty-one percent of the expenditures were classified as having fair payouts and 32 percent classified as poor or no payout.

There are, of course, many types of individual cost-benefit decisions which must be made that contribute to the total investment in air pollution control equipment, and these decisions vary, as would be expected, with local conditions. For example, refineries in the Los Angeles area have installed extensive sulfur-recovery facilities and have restricted usage of high-sulfur fuels as the result of severe regulations. The Los Angeles Air Pollution Control District estimates that the refineries emit only 55 tons of sulfur dioxide each day and recover hydrogen sulfide equivalent to 800 tons per day of sulfur dioxide emissions.[209]

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*Five percent is estimated from the total cost of pollution control of 10 to 15 percent of overall cost.

TABLE 22

PETROLEUM REFINERY AIR POLLUTION CONTROL EXPENDITURES BY TYPE OF EMISSIONS

Type of Emission	Expenditure	Percent of Total
Sulfur Compounds	$ 46,700,000	22.8
Hydrocarbons (Combustion)	46,500,000	22.6
Hydrocarbons (Recovery)	50,500,000	24.7
Smoke and Particulates	32,200,000	15.7
Odors and Fumes	29,100,000	14.2
TOTAL	$ 205,000,000	100.0

Construction costs for a sulfur-recovery plant will, of course, vary with capacity. As an illustration, construction cost for a 27-ton-per-day unit was estimated at $325,000, with an operating cost of $165 per day.[210] The facilities to recover hydrogen sulfide from the refinery streams for feedstock to the plant added $320,000, with an operating cost of $280 per day. In this case, the investment required to recover each ton of sulfur per day was approximately $24,000, with an operating cost of $16.5 per ton per day. The sale of liquid sulfur helps offset the cost of the recovery facilities.

A detailed survey of sulfur-recovery facilities and their capacities is not available, but an indication of their widespread use may be obtained from related surveys. An API survey of expenditures for fuel products desulfurization in 1966 stated that the industry had invested $110 million in acid gas removal, mercaptan extraction and sulfur conversion facilities.[211]

A similar survey reported that in the 1961-1966 period, refineries constructed 21 sulfur-recovery plants at an approximate cost of $12.6 million. The total expenditures for sulfur-compound emissions control in the 1956-1966 period was approximately $46.7 million (Table 22).

As another example, smokeless flares are readily available today, and it is probable that all new refinery construction will utilize them. Cost of construction of a complete flare system is substantial. A new flare system being considered for only a group of process units (i.e., only a portion of a new refinery) has been estimated to cost as much as $500,000. The conversion of existing flares to automatic smokeless flares is also costly. The cost will undoubtedly vary greatly depending upon the specific installation; however, as an illustration of cost, one conversion at a major refinery involved a capital expenditure exceeding $100,000. This installation will require up to 20,000 pounds per hour of steam, and the given capital cost does not include the equivalent capital cost of steam generation facilities.

One major refinery installed floating roofs and a tank vapor-recovery system at a cost of approximately $4 million in the 1950's. These installations were required to conform to Los Angeles area regulations.

A detailed survey of the number of carbon monoxide heaters and boilers installed in the U.S. is not available, but it is believed that more than 50 percent of the major refineries have these installations. Construction of 33 carbon monoxide combustion units at a cost of $33 million in the 1961-1966 period was reported in the *Oil & Gas Journal*.[212]

There is, of course, an economic return from some pollution control efforts. Sulfur recovery has already been mentioned, although at current sulfur price levels, economic returns are questionable. There is substantial economic incentive for good recovery of the catalyst from the gases emitted from catalytic-cracking regenerators since the various catalysts are priced at $300 to $800 per ton.

2. Other Operations

Evaporative losses from storage tanks have not been shown to contribute significantly to air pollution. Control measures taken by the industry generally have been motivated by the desire to reduce product losses.

In a 1963 study by Los Angeles of a limited vapor-for-liquid recycle system, some cost figures were developed as follows:

- It would cost $79,000 per daily ton to reduce hydrocarbon emissions from underground service station tanks by installing submerged fill connections.
- It would cost $538,000 per daily ton to reduce hydrocarbon emissions at the service station by installing a vapor return line from the underground tank back to the truck.
- It would cost $300,000 per daily ton to reduce hydrocarbon emissions from the automobile. These emissions would include those lost via exhaust, blowby and evaporation.[213]

Los Angeles further stated that the equities involved in requiring large expenditures to control small quantities of air contaminants at any source would have to be carefully weighed.

In 1967, Arthur D. Little, Inc. investigated the overall vapor-for-liquid recycle concept. In general, they found that, for an integrated vapor-for-liquid recycle system, the economic incentive to convert did not exist.[214]

In one evaluation, Arthur D. Little only reviewed the conversion of service stations and transport trucks. Vapors in this case were returned from the automobile to the underground tank, and from the underground tank to the truck. No terminal alterations to permit vapor recovery at this point were included in this evaluation. The cost figures that they developed are as follows:

Terminal Size	Investment per Terminal System
1,000,000 gallons per month	$ 60,250
5,000,000 gallons per month	302,250
10,000,000 gallons per month	604,500

In the above evaluation, the terminals were assumed to have in their fleets 1, 4 and 8 trucks, respectively, which would have to be converted, and to supply 25, 125 and 250 service stations, respectively, where facilities would have to be revised.

In another evaluation, Arthur D. Little reviewed the conversion of terminals in addition to service stations and transport trucks. In this case, the terminals would have vapor-recovery systems to prevent losses to the atmosphere while loading trucks. These cost figures are as follows:

Terminal Size	Investment per Terminal System
1,000,000 gallons per month	$136,450
5,000,000 gallons per month	399,650
10,000,000 gallons per month	727,500

C. Control of Noise and Light

Noise and light, while more in the nature of annoyances than pollutants, can become problems, especially when refineries near urban areas are involved.

As in most other industry operations, complexity makes it difficult to determine the cost of noise abatement. From the limited information available, it appears that such a program at a typical refinery of 100,000-barrels-per-day capacity could range from $100,000 to $250,000.

Light from refinery flares is negligible under normal conditions, while the cost of facilities to conceal such flares may occasionally reach $150,000 to $250,000.

Chapter Four

EXPLORATION AND PRODUCTION

The importance which the petroleum industry attaches to pollution control in drilling and producing operations is aptly indicated by the large investment required and provided, particularly offshore, to prevent mishap and to control our valuable petroleum resources.

This investment is made for sound business reasons as well as for meeting regulatory requirements and societal needs, since the destruction of an offshore platform or premature depletion of a reservoir by reason of ineffective safety or other control procedures would result in major financial losses to the companies concerned.

In considering pollution control in the petroleum industry, it must also be remembered that loss of oil represents a basic loss of the principal salable product for which oil exploration and production is organized and conducted. Control and conservation of oil and gas are under constant study by the oil industry to ensure that the loss of both energy and product is held to a minimum.

Section 1.
BASIC OPERATIONS FACTORS

The starting point of the tremendous effort that must be made to supply the petroleum resources needed by the United States is exploration to locate economically recoverable quantities of crude oil and natural gas. Exploration activities are spread throughout those areas that geologists indicate may have suitable formations for the containment of oil or gas. In the search for these resources, various exploratory methods are used with varying degrees of success.

Geophysical and geological operations for petroleum exploration are not major contributors to either the threat of or actual pollution. These activities involve small quantities of material and operate for such a short period of time that they do not in general influence the environment. However, the final step in the exploratory process is always drilling of the exploratory well.

The relatively simple exploratory process of locating drillable prospects by reflection seismograph surveys will continue to be effective in many areas offshore for some time to come.

Moreover, in the Gulf Coast, offshore and onshore, finding and outlining a field on a piercement salt dome is frequently far less simple than finding the dome itself, because of structural and stratigraphic complexities. Many exploratory and development dry holes commonly are required.

Deeper drilling, whether or not to basement,* is likely to discover many more natural gas fields than crude oil fields. Most of the crude oil in the United States--in fact in the world--is produced from depths shallower than 10,000 feet. Below 15,000 feet, natural gas and gas condensate fields predominate. The distribution of crude oil and natural gas fields at shallower depths is somewhat haphazard.

In general, pollution engendered by drilling, completion, producing and pipelining operations with present good operating practices is not a significant

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*"Basement" is defined as an underlying complex of rocks which is beneath the sedimentary sequence and is unattractive as a prospect for petroleum.

problem. When properly controlled, with the exception of a few spectacular accidential situations, the problem has been handled to the satisfaction of all parties concerned.

Extensive operational experience in pollution control on land has equipped the oil and gas industry for handling similar problems in the newer province of offshore operations. However, the industry has also had experience in offshore operations dating back some 35 years, and although these operations have recently increased in intensity, pollution control techniques have kept pace.

The pollution control procedures involved in offshore operations are similar to land operations, although the control problem generally is more difficult because of the hostile environment in which the equipment must operate. The trend toward drilling in deeper water at a greater distance from land has led to the development of better, more comprehensive safety features and planning procedures to anticipate and handle possible sources of water pollution. These new developments enable the industry to minimize water pollution and help to control any spills that occur from unanticipated or accidental situations.

The United States Geological Survey (USGS) Outer Continental Shelf (OCS) Rules 8 and 9 for the Gulf of Mexico were revised October 30, 1970, greatly increasing safety equipment requirements for pollution control. In the Department of the Interior Environmental Impact hearings on offshore leasing in the Gulf of Mexico held in New Orleans on September 8 and 9, 1971, one company testified that more than $11 million was being spent and 50 new employees added to comply with the new rules in the Gulf offshore Louisiana.

In many instances, however, onshore pollution presents a more difficult problem to oil operators than does offshore pollution. For example, the production of salt water must be closely controlled and regulated on land to prevent pollution of water resources and contamination of land areas and to prevent destruction of vegetation in farming areas. This same problem does not exist at sea, since the water produced in conjunction with offshore operation, when cleaned of fresh entrained oil, is generally compatible with the sea environment.

Removal of oil from salt water to the standards required by the USGS is not easy on a reliable basis with mechanical equipment in the small areas available on offshore platforms. Regulation OCS 8, Gulf of Mexico, requires that oil/water separation equipment be designed to remove to 50 parts per million and at no time discharge more than 100 parts per million. The removal of oil adhering to sand produced with the oil is also a problem.

The principal difference between offshore and land operations is the possibility of catastrophic failure of the offshore well due to damage or destruction by shipping or storms. The potential for a major catastrophe is greater than on land because of the grouping of wells on platforms for many reasons and the greater logistics problems in controlling a fire or a well out of control. Operating in a severely corrosive atmosphere such as the sea-air interface has placed great emphasis on protecting equipment exposed to this hostile environment. The net result is to employ highly sophisticated, remotely controlled or automatically actuated safety devices. Basically, these systems are designed to be fail-safe; that is, to be normally closed and to be opened only if any of a number of programmed all-clear conditions exist.

To reduce still further the possibility of pollution incidents, safety equipment and procedures have been and are being incorporated into the basic operating procedure for all facets of the exploitation of petroleum reserves. The complexity of the equipment used, and the quality of the training required for the operators, approach or excel those employed by any other industry. In this regard, it is well to remember that even the most sophisticated equipment requires man to exercise judgment to ensure control in any given situation. Human error cannot be completely engineered out of the system; it can be minimized by training, including simulated emergency exercises.

Improvements in preventive actions have reduced spills or uncontrolled flows from wells to rare occurrences. Where such events have occurred, the petroleum industry has acted vigorously to devise means of preventing future pollution. Prevention and control of oil field pollution requires a never-ending effort involving research, planning, personnel training, equipment, safety features, automation and supervision.

The following sections of this report relate the activities involved in exploration and in drilling, producing and repairing oil and gas wells for the purpose of bringing out their relation to pollution problems and methods of controlling pollution. The NPC report, *Impact of New Technology on the U.S. Petroleum Industry 1946-1965*, contains reasonably up-to-date and detailed information on general exploration, drilling and production practices, reservoir exploitation and offshore operations, and may be referred to for further understanding of these operations of the petroleum industry.

Detailed coverage is given in this report of exploration and production in water-covered areas because these areas combine the normal underground problems found in land operations with the problems of operating through water, a medium which exerts its own unique influences on operations, with different possibilities for mishaps and different effects of oil spills. Land pollution problems which are unique to land operations are covered separately. Since the potential for air pollution from operations over water and land is essentially the same, separate treatment is also given to this subject.

Section 2.
EXPLORATION OPERATIONS AND POLLUTION CONTROL

Both the maintenance and potential expansion of the petroleum industry's domestic crude oil producing capability depend on a continuing program of exploration for, and discovery of, new oil reserves. Exploration operations by the industry, both offshore and on land, are vital and critical to meet the increased demands for U.S. crude oil. Since a growing percentage of new reserves is expected to be found offshore, exploration and leasing must proceed as a constant and continuing effort to secure geological and geophysical data to evaluate the petroleum potential of all possible offshore areas. Lead time and continuity of offshore sales are essential to ensure efficiency in exploration for discovery of new reserves so vital to the national economy.

Exploration prior to drilling operations poses an extremely minor threat of pollution either on land or to water-covered areas, and adequate precautions against the possibility of pollution are incorporated as integral parts in the exploration process. Procedures for obtaining the raw geophysical and geological data required for evaluation of the petroleum potential of an area involve only temporary *in situ* utilization of instruments and systems and are of such short duration that the environment of the area is rarely and only momentarily disturbed.

A. Water-Covered Areas

1. Operations

Gathering of geophysical and geological data for petroleum exploration in water-covered areas encompasses three categories of activities:

- Geophysical surveying to map various specific earth conditions
- Bottom sampling to collect geologic materials from the sea bottom
- Core drilling to sample bedrock below the sea bottom

a) Geophysical Surveying

The specific earth conditions commonly surveyed by geophysical methods to obtain data for evaluation of the petroleum potential of an offshore area are--

- Magnetic field
- Gravity field
- Seismic (acoustic) sounding
- Heat flow
- Seawater chemistry.

Instrumentation to obtain these types of data may be towed by a survey boat, lowered to the sea floor from the boat, or utilized aboard the boat.

1) Magnetic Field

A marine magnetic survey is accomplished by towing a magnetometer behind a survey boat in a "fish" about 24 inches long and 8 inches in diameter on an instrument cable several hundred feet long. The signal, a measure of the intensity of the earth's magnetic field, is recorded on tape or chart aboard the survey vessel. The data are usually processed ashore.

Given the ship's location on the grid survey, a map of the magnetic intensity can be prepared to show basement structural and compositional trends. The data may be used, with certain assumptions, to calculate the depth to basement.

2) Gravity Field

The earth's gravity field may be measured by positioning a survey boat at a station and lowering a standard gravity meter in a pressure vessel overside to the sea bottom. The instrument in its pressure vessel weighs several hundred pounds and is equipped with remote leveling and readout controls. The gravimeter signal is read, recorded and corrected for certain variables at the surface. Gravity data obtained from a series of such stations permit compilation of a gravity map of a survey area.

Another means of obtaining gravity data employs the recently developed underway gravimeter which has largely replaced the sea-bottom gravimeter. This instrument consists of a group of accelerometers on a stable table aboard ship. The signal from the accelerometers, when corrected for boat and earth motion, gives a measure of the earth's gravity field. When combined with the navigational data from the survey grid, a gravity map may be prepared.

A gravity map, from either a standard gravity meter or an underway gravimeter, is valuable to the geologist in determining the structure of a sedimentary basin, particularly in offshore areas of salt tectonics.

3) Seismic (Acoustic) Soundings

Seismic (acoustic) soundings utilize the physical principle of measuring the time required for a signal (sound) to return to the surface after being reflected from a target, i.e., an echo. The signal returns or echoes, when properly processed, permit construction of a map or cross section showing the positions of the reflectors. The frequency and power of the acoustic signal determine the distance or penetration and resolution of the system. Seismic signals that penetrate the earth and are reflected from various rock strata are of relatively low frequency, e.g., below a few hundred hertz (Hz). Acoustic sounding signals, such as fathometer and sonar signals, have higher frequencies (ranging from a few kilohertz to several hundred kilohertz) which penetrate water but are reflected by the rocks and mud of the bottom.

The fathometer, with acoustic transducer and receiver attached to the hull of a survey boat, gives a record of water depth along the boat path and provides data for construction of a bathymetric map of the survey area. Such a topographic map of the sea bottom is important to the geologist in evaluating areas where clues to the subsurface structure are detectable at the surface.

The geological sonar, sometimes called "side-looking sonar," utilizes transducers and receivers mounted in a "fish" which is towed several hundred feet behind a survey boat on an instrument cable. The size of the fish, a function of the power requirement of the system, may vary from 1 to 5 meters in length. The acoustic echoes from the sonar are monitored and recorded aboard ship. Later shore processing of the sonar readings provides an echo map of the sea bottom which resembles an air photo of the earth. From the mosaic of sonar strips the geologist can interpret the geomorphology which, when combined with seismic information, can be used to construct a structure map of the offshore survey area.

Marine seismic systems use many varied energy sources to generate signals to penetrate the sea bottom. The original acoustic source universally used was dynamite, but today more sophisticated energy sources with less danger and less pollution hazard for offshore areas are available. These sources include encapsulated explosives (small charge), sparkers (electrical spark gap), exploding wires, compressed air guns, carbide guns, gas (propane-oxygen) guns, and electromechanical and mechanical transducers. In marine surveys, all of these modern sources are operated over the side or close behind the ship. The return signal, or echo, is received by a variable length, multigeophone cable towed a few hundred feet behind the acoustic source. The signal is monitored aboard ship and recorded for further processing onshore. Bottom penetration of the signal may vary from 20 to 20,000 feet, depending upon the power and frequency of the acoustic source.

The output of the marine seismic system is a cross section upon which geologic strata are delineated according to their velocity contrast (reflectivity) to the acoustic energy. From a series of such cross sections across an area of interest, the geologist can view a three-dimensional model of the earth's structure in the area.

4) Heat Flow

Heat flow through the sea bottom is measured at a ship's station by lowering an instrument to the bottom. Either a slim thermistor probe, which penetrates the bottom muds for a few feet, or a thermistor blanket, which covers several square feet and simply lies on the bottom, can be used to measure the differential temperatures used to calculate heat flow. The signal can be recorded in the instrument at the bottom and read upon recovery, or the instrument can be run on an instrument cable and the signal observed aboard the ship. Plotting of the data recorded for numerous stations permits mapping of heat-flow variations within a survey area. Heat flow is believed to be indicative of the general lithology of the rocks below the measurement station.

5) Seawater Chemistry

Chemical measurements of sea water are made on continuous or batch samples, either while a survey ship is under way or is on station. The usual seawater measurement for petroleum exploration is to determine the presence of one or more hydrocarbons or perhaps some trace element. Various hose and pump combinations are used to sample water from the surface to the bottom and from a standstill to maximum boat speeds. The water samples may be analyzed either aboard ship or bottled for analysis later onshore. The analytical data are plotted to provide maps of the concentration of hydrocarbons or of some other chemical parameter. Such maps provide additional information for the geologist in interpreting the petroleum potential of an offshore area.

b) Bottom Sampling

In offshore exploration for petroleum, rock samples from the sea floor provid the geologist with specific geologic information.

The bottom samples are recovered from the sea-floor surface by wire-line dredges, grabs or gravity corers. Sometimes a television-equipped robot, controlled from the surface through an instrument cable, is used to grab or dredge a specific sample. A diver at shallow depths, or a manned submarine at greater depths, can sample the bottom with various scoop, grab or claw devices.

Bottom samples are essentially surface samples of the sea bottom and do not effectively penetrate bedrock. The samples are usually sent to a geologic laboratory ashore for description of rock type, composition and fossil content and measurement of porosity and permeability. The analytical data, in conjunction with structural data from geophysical surveying, are used to construct a geologic map of the surveyed area.

c) Core Drilling

Core-drilling operations of the petroleum industry are conducted on the continental shelves and slopes by floating drill ships utilizing relatively small drilling equipment but standard drilling procedures (see Section 3). The cores drilled from the bedrock are sent ashore to a geologic laboratory for description and analysis, including rock type and composition, porosity, permeability and fossil content. The information from the laboratory, in conjunction with the seismic structural data, allows the geologist to add qualitative data of rock properties and the third dimension of depth to geologic maps and cross sections.

Core drilling is generally categorized by the depth of penetration. The breakover from shallow to deep coring is about 500 feet.

In the past, when core holes have been drilled to penetrate less than 500 feet beneath the sea floor, sea water has generally been employed as a drilling fluid, and surface casing has not been set and there has been no reentry means. The coring rigs do have capability to cement a hole if flows of oil, gas or water are encountered.

Deeper core holes (over 500-feet penetration) in shallower waters (approximately 100 feet or less) have been generally drilled with all the pressure control equipment applicable to conventional deep-well offshore-drilling operations (discussed in Section 3 of this chapter). Surface casing is cemented, there is a reentry means, and drilling mud and cementing equipment are available for well control.

The federally funded Joint Oceanographic Institute Deep Earth Sampling (JOIDES) research program involves collecting deep cores in both deep water off the continental slopes and the abyssal deeps. Until 1970, this program operated without a reentry means or the setting of casing. In practice, if petroleum is encountered or even suspected, drilling is terminated and the hole is plugged with cement. Figure 11 shows the floating drilling ship *Glomar Challenger* used in the JOIDES project and the extent of its recent activities.

2. Sources and Control of Pollution

Sources of pollution are minimal in geophysical surveys. With the advent of non-dynamite seismic sources, even the occasional fish kill is no longer a problem. Bottom sampling is not a source of pollution. Therefore core drilling affords the only possible source of significant pollution in the form of a blowout, and the danger increases with depth of penetration. However, the probability of a blowout due to coring into an oil reservoir, which would be a pollution source, is extremely low. Such a blowout could most probably be controlled with standard core-drilling safety techniques. Penetration of high-pressure gas pockets during core-drilling operations at shallow depths is a potential danger to both drilling rig and crew, but the gas is usually in small volumes and does not constitute a pollution hazard.

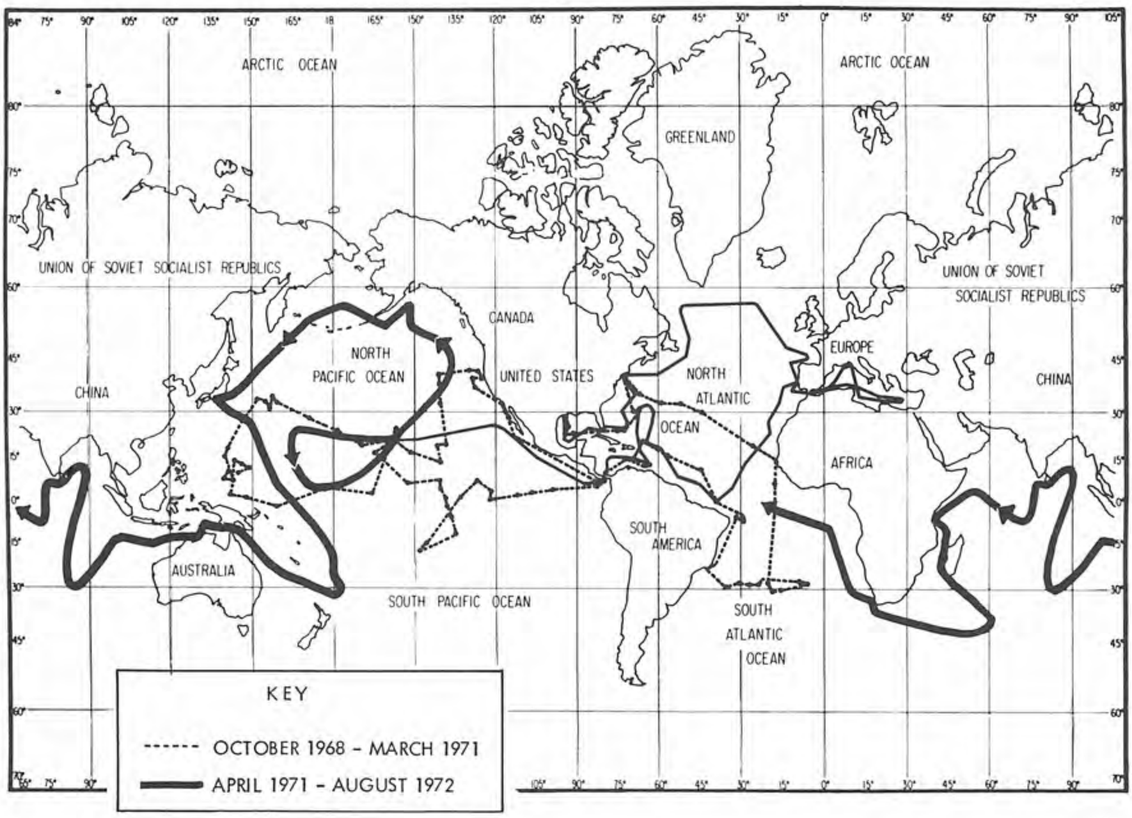


Photo and Chart: Courtesy of National Science Foundation.

Figure 11. Glomar Challenger and Glomar Challenger Track Chart.

Pollution prevention during core-drilling operations is adequately handled by use of weighted muds and cemented surface casing on core rigs. Coring is undertaken only by permit from USGS, and drilling operations comply with regularly revised USGS regulations. Control procedures may vary as the predicted dangers vary from area to area.

The history of petroleum exploration in water-covered areas has demonstrated that danger of pollution is only minor. In the past 10 years, thousands of core holes have been drilled by the petroleum industry (under USGS and Canadian government permits) on the shelves and slopes of all the U.S. and Canadian coasts, and no pollution has resulted.

The JOIDES deep-water coring program had drilled 236 core holes by December 1970. Total footage drilled was 186,278 feet; coring totaled 50,065 feet with 32,625 feet of core recovered. In water as deep as 20,146 feet, core recovery was accomplished with 604 feet of subocean penetration. During the program, coring was achieved with a maximum of 3,334 feet of subocean penetration in 14,778 feet of water. No pollution has resulted from the JOIDES program.

B. Air Pollution

The potential for air pollution caused by the exploration for oil and gas is quite small, primarily because of the small number of rigs which usually operate in any given area at one time and because modern drilling operations do not contribute significantly to air pollution. For example, in 1969 only 550 exploratory gas wells were drilled throughout the 32 states which produce gas in the United States. That is an average of only 17.2 such wells per state.

Geophysical surveys for oil or gas do not contribute significantly to the air pollution problem, because seismic operations are generally conducted in unpopulated areas and the magnitude of induced energy and explosives is minor. Exploratory core-drilling operations may emit small quantities of contaminants intermittently into the atmosphere and, as described earlier, penetration of high-pressure gas pockets at shallow depths can be a potential danger. The possibilities of air pollution from well testing, blowouts, drilling for natural gas, air and gas drilling, gas venting and well stimulation are covered in Section 3.

C. Land Pollution

Although ground pollution is possible in exploration activities, there is more potential danger in petroleum production, particularly during the drilling operation. Drilling problems are described in Section 3.

In populated areas, noise and shocks from geophysical exploration activities are being sharply reduced with new technology. A "thumper," which utilizes a heavy vibrating pad to send out acoustic waves, performs geophysical explorations formerly done by setting off explosives in shallow holes. In 1969, 35 percent of all geophysical work in the United States was done without explosives, instead, nondestructive acoustic sources such as the "thumper" were used.[215]

Uncased seismic shot holes can cause pollution of shallow freshwater sands. Some states now have regulations requiring proper plugging.

Section 3.
PRODUCTION OPERATIONS AND POLLUTION CONTROL

In the period since World War II, the development and use of both new and improved technology, as well as the more effective application of previously known technology, rapidly accelerated in the production phases of the petroleum industry. Through extensive research, new tools, techniques and procedures were discovered, and widespread testing was undertaken to determine their practical effectiveness. The full impact of many of these developments has not yet been ascertained.

These technological developments led to major improvements in both inland and offshore drilling rates and depths; in the amounts of crude oil obtainable from previously discovered fields; in the rates of production under sound conservation practices; in the costs of drilling, development and production; and in the control of pollution of air, land or water from production operations. From this experience and in the light of the most recent technological developments, a momentum has been achieved that can be expected to result in additional developments and continued favorable impact on these areas of operations in the 1970's and beyond.

A. Water-Covered Areas

Petroleum exploration and development on the Outer Continental Shelf (OCS) is regulated by the Federal Government, through the USGS, on a regional basis, with separate regulations applying within USGS regions. Within state waters, inland bays and rivers, the detailed rules by which the industry must abide are developed and enforced by various governmental agencies--federal, state, county, city, etc.

The federal Water Quality Improvement Act of 1970 went into effect in April of that year, requiring the reporting to the U.S. Coast Guard or the Environmental Protection Agency of any oil spill in "harmful quantities" into the navigable waters of the United States. A "harmful quantity" has been defined as "a visible sheen or iridescence." During 1971, under authority of the Refuse Act of 1899 (Section 13 of the Rivers and Harbors Act of 1899) and an Executive Order issued by the President on December 31, 1970, the U.S. Corps of Engineers published rules requiring an application for permit to discharge into the navigable waters or tributaries of the United States any discharge except sewage or rainwater runoff from streets. The Environmental Protection Agency must approve the water quality aspects of the discharge before the Corps of Engineers issues a permit.

With the implementation of these two Acts, the Federal Government has taken an active role, preempting state and local authority over pollution control in inland and territorial waters.

Such regulatory activity is not entirely consistent with the rules which apply to area of the OCS. Because of numerous "local" procedures followed by the industry in these inland waters, one could not possibly hope to include all of them in discussing oil and gas operations. For these reasons, this section will concern itself primarily with federal regulations and procedures which are followed.

The first oil well drilled in the open, unprotected waters of the Gulf of Mexico was in 1937, in an area which was to become known as the Creole Field, approximately 1.5 miles offshore Louisiana. Prior to that, offshore oil and gas production was limited to that accomplished beneath the ocean off California by using directional drilling techniques from shore and pier locations. Significant development of offshore petroleum resources did not commence until 1947. The Outer Continental Shelf Lands Act was passed in 1953, after which widespread development of these resources took place. Offshore petroleum exploration is now being conducted in nearly 40 countries worldwide.

It is estimated that over 14,000 offshore wells in U.S. federal and state waters had been drilled through 1970, if multiple completions are counted as one well. Approximately 9,000 wells have been drilled on the OCS, with more than half of these completed as wells productive of oil or gas. Yet in only 25 of these wells were blowouts experienced, which is one of the prime sources of pollution. Furthermore, only three oil-spill incidents (one off the coast of Santa Barbara in 1969 and two in the Gulf of Mexico in 1970) have been of a magnitude to cause any serious pollution threat. Obviously, the petroleum industry has acquired considerable experience in preventing pollution during the search for and production of petroleum resources and has been highly successful in keeping serious pollution threats to a minimum.

Even the spectacular occurrences in Santa Barbara and the Main Pass area of the Gulf of Mexico are relatively minor compared to the naturally occurring oil seepages and the large volume of crude lost by enemy sinking of tankers during World War II. In connection with both the accidential loss of crude and the naturally occurring oil seepage, experience indicates that the biodegradable nature of hydrocarbons will minimize irrevocable ecological damages in most cases. Recent scientific investigations have demonstrated that the elimination of hydrocarbons on the surface of the water proceeds at a relatively rapid rate even under conditions which in the past have been considered adverse for this type of natural environmental cleansing.

Permanent drilling and producing fixed platforms have been installed in water depths up to 340 feet in the Gulf of Mexico. Several aerospace companies have joined forces with oil companies in the design of underwater production systems, though these have yet to be field tested. There have been 32 sea-floor well completions made offshore California and in the Gulf of Mexico, but this experience with sea-floor completions is still limited because the techniques are relatively new. Certainly underwater structures and completions are needed and may be used in specific situations, but at the moment, in many of the circumstances that may be encountered offshore, surface platforms may offer more safeguards for environmental control. All of the above methods may have future application as the search for hydrocarbons is extended to greater water depths.

The search for and production of petroleum resources inevitably carries the potential to create hazards. There exists at all times the possibility of failure of the offshore drilling well or the platform installation due to damage or destruction by shipping or storms, but by comparison with many other installations and activities outside the petroleum industry which have been in the path of catastrophic weather disturbances, offshore production operations have fared remarkably well.

Pollution from offshore oil operations can result from blowouts during drilling, rupture of well casing due to storm or ship collision, spillage of oil in storage at the surface, pipeline leaks, failure of surface production equipment or accidents caused by human errors during production operations. As yet, no offshore oil spill has been traceable to earthquakes.

Fixed permanent platforms are undergoing continual changes in design and construction. An excellent safety record has resulted, although several have been destroyed by hurricanes and other violent storms. The American Petroleum Institute has recently compiled *Recommended Practice for the Planning, Design and Construction of Fixed Offshore Platforms* to establish guidelines for their construction.

The procedures and equipment to prevent release of oil and gas from offshore operations are already available. Drilling technology, for example, provides for control of unexpected oil or gas pressure through the use of many safety devices, including heavy drilling mud, well casing and blowout preventers. Subsurface valves close the well automatically if producing wellheads are broken by storms. Valves in gathering lines shut off flow when loss in pressure signifies a leak. Electronic navigation devices are used to guide ships clear of equipment and through shipping lanes in which oil and gas operations are not permitted. Offshore platforms are equipped with navigation devices to warn ships which ply the water around producing fields, and navigation charts are updated to show the location of new installations. Weather services and communications are employed to provide advance storm warnings and thus allow exercise of safety precautions and evacuation of personnel if necessary. The surprise and the unexpected elements in many of the events leading to release of oil and gas set the stage for the "accident," but in view of the state of development of both prevention procedures and equipment, the occurrence itself must be attributed to human error or equipment failure, or a combination of the two.

The Outer Continental Shelf Lands Act of 1953 grants to the Secretary of the Interior, and under his direction the USGS, the authority for supervising exploration, drilling and production offshore. These regulations have been further supplemented, as conditions warranted, by specific orders issued by the Regional Oil and Gas Supervisors of the USGS, who must also approve proposed plans for exploration, production and related operations and who inspect operations in progress at their discretion. These orders are most versatile and differ between the Gulf Coast Region and the Pacific Region because of different geological and operating conditions. That these regulations, procedures and practices have been effective is shown by the very low incidence of serious acts of pollution in offshore operations over the years.

After the Santa Barbara spill, the OCS operating regulations, Title 30 CFR 250, the Pacific Region orders and the Gulf Coast Region orders were all revised to reflect more stringent procedures. The petroleum industry was given the opportunity to comment and suggest changes to further strengthen the operating regulations. Most of the changes made in these final orders were already being practiced by operators offshore. These changes have increased the burden of responsibility on the operators to ensure that pollution is further reduced.

Following the 1970 incidents in the Gulf of Mexico, the USGS further strengthened operating rules, particularly OCS 8 and 9. These changes required significant additions in safety devices and testing and inspection procedures, as well as many new pollution control facilities.

In addition to these regulations and rules of procedure that must be followed by the industry in operating offshore, other governmental agencies must be contacted for approval of various items. The U.S. Coast Guard, advised by a Merchant Marine Council, maintains a Merchant Marine Safety Program which provides for safety inspection and regulation of floating vessels, their construction, repair and equipment, and the investigation of marine accidents and acts of incompetency and misconduct.

The USGS is responsible for design approval and inspection of fixed drilling and production platforms. Platform details must be submitted to the USGS for approval prior to installation. The Corps of Engineers is responsible for the delineation of sea lanes and for preventing obstruction to navigation. Operators must obtain their approval to install platforms at specific locations. The U.S. Coast Guard is responsible for aids to navigation as well as other safety items such as life rafts and firefighting equipment and approves these items on all fixed installations.

In addition to these agencies which perform the function of approving an operator's exploration plans and platform installation, the industry itself has joined forces in taking steps to prevent pollution. In the Gulf, operators have formed the Offshore Operators Committee which provides technical advice and assistance to the USGS and other agencies that formulate rules and regulations offshore. Many other cooperatives have been formed, including Clean Seas, Inc.; Clean Bay, Inc.; Pice Co-op; Washington State Oil Spill Co-op and Corpus Christi Oil Spill Clean-Up Organization.

In general, water pollution resulting from offshore oil and gas operations has not been severe and has been handled, so far as is known, with no permanent effect on the ecology. In cases where spills or blowouts have occurred, the petroleum industry has acted rapidly and vigorously to devise means of preventing future occurrences of similar incidents.

Basically, the accidents that occur in petroleum operations are similar to other accidents--fire, airplane and other vehicle crashes, and structural failure of dams and buildings--in that they are the result of human error or equipment failure, or both. Recognizing the human inclination to err and the weakness that may develop undetected in equipment, perhaps we cannot hope to eliminate these accidents completely. However, the rare accident can create damage and the industry must continually reexamine safety technology in petroleum operations and continually improve procedures and practices, particularly procedures that guard against human error and equipment failure. Continuing education and training of personnel at all levels to prevent accidents and, should they occur, minimize their results, is industry practice.

As technology is improved, regulations can be revised and updated. To accomplish this, government and industry representatives must continue to work together.

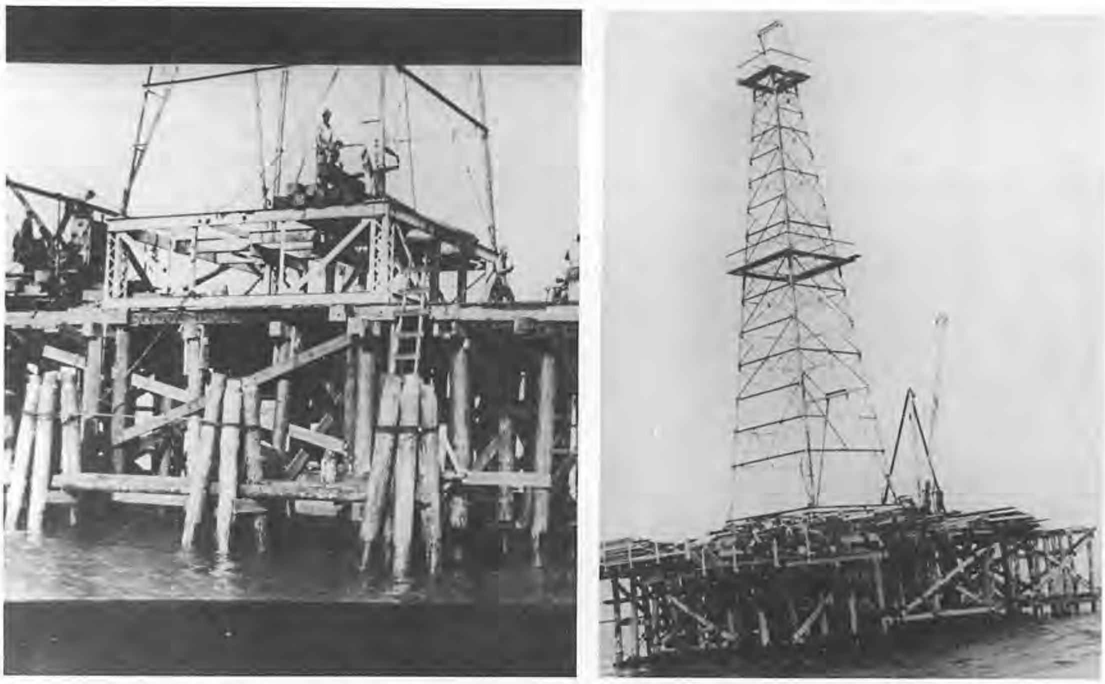
1. Drilling

a) Platforms and Rigs

Offshore petroleum drilling operations are essentially the same as those for onshore drilling except that the rig is supported by a structure that rests on the bottom of the sea or on a floating vessel rather than on land. The type of offshore structure which supports the drilling operation varies from platforms on piles, jack-up structures and floating vessels to man-made islands.

The original platforms were timber and steel piling pier, similar to the one shown in Figure 12. These quickly gave way to barge-mounted rigs for shallow water and to what is known as the template platform, a unit which consists of a number of vertical tubes interlaced by horizontal and diagonal members. This structure extends from the ocean-floor mud line to a location above the water surface. Pilings are driven through the vertical tubes and the deck is placed above the pilings. Figure 13 illustrates this design.

The original platforms consisted of a great number of steel tubular pilings as small as 10.75 inches in diameter and were located in water depths less than 50 feet. As technology has improved and operational water depths have increased to 340 feet, the number of pilings per platform has decreased, while their diameters have increased to as much as 48 inches and the penetration into the soil may be as great as 300 feet. Large, ice-resistant platforms have been constructed with legs as large as 17 feet in diameter.



Photos: Couresty of J. Ray McDermott & Co., Inc.

Figure 12. 1938 Platform, McFaddin Beach, Texas.

Photo: Courtesy of J. R. McDermott & Co., Inc.

Figure 13. Jacket Loaded Aboard Cargo Launch Barge Prior to Installation in the Gulf.

With offshore operations moving into deeper water, thereby presenting more complex structural design problems, the more competent design engineering offices today have turned to the use of digital computers for the structural analysis of oil-well drilling and producing platforms. Many variations of computer programs for loading analysis and design are being used; however, there is considerable similarity in the programs and objectives.

The original platforms were installed with available derrick barges and marine equipment. These soon proved to be inadequate for the task at hand, particularly in locations remote from shoreline and harbor protection. Today, a number of derricks with lift capacities of 250 tons placed aboard barges 90 feet in width by 300 feet in length are available for open-ocean oil operations. The most recent innovation in this respect is the enlargement of the barges to 100 feet in width and 400 feet in length and the escalation to cranes with lift capacities of 500 tons.

The self-contained platform shown in Figure 14 (i.e., one containing all of the necessary materials and equipment for drilling as well as personnel housing) was selected for the initial drilling operations and has continued to be a well-accepted method of drilling prolific, proved areas.

This platform places all materials, supplies and personnel on a fixed structure in a compact, well-organized manner, which provides the most ideal arrangement for drilling purposes. No doubt, all operations in the offshore industry would be conducted from self-contained platforms if costs could be disregarded. If a great number of wells are to be drilled from a single location, the lower daily drilling costs of a self-contained platform will pay for the added structural costs required before drilling operations commence.

Photo: Courtesy of J. Ray McDermott & Co., Inc.

Figure 14. Self-Contained Drilling Rig (1965, Deck Size 66' x 118').

The use of a floating drill tender or vessel to support supplies, machinery and personnel, thereby reducing the size of the fixed platform, is another effort to reduce platform cost. Figure 15 depicts this type of drilling operation.

The initial adaptation of mobile drilling equipment for the open sea consisted of a barge with an elevated deck to support drilling machinery, supplies and personnel. These barges used various methods to maintain vertical stability while being lowered to the seabed. In general, these units have been limited to use in less than 50 feet of water.

As operators extended mobile units to water depths beyond 50 feet, the jack-up drill barge came into being. This barge, a type of which is shown in Figure 16, consists of legs which extend from the flotation element into the ocean bottom with a jacking system to raise the flotation element above the water surface, or of legs attached to a mat which extends to the ocean bottom and a flotation element which is jacked clear of the water surface. This barge has many variations; some have as many as 10 individual supporting legs, others as few as 3. Some use individual mat supports on each leg, and in other instances a mat is attached rigidly to all of the legs. On some of the more recent designs, the legs have been tilted outward to give an increase in the base dimension at the mud line and create structural stability for the greater water depth. Jack-up drilling units have been constructed with rated operating water depths as great as 300 feet.

Concurrently with the jack-up drill barge, the bottom-setting-column stabilized unit was developed, which consists of a lower mat attached to an upper deck by large-diameter tubular members. The column diameters vary up to 30 feet and the units have rated operating water depths up to 175 feet. However, the majority of these rigs are limited to approximately 70 feet of operating water depth. Their greatest attribute lies in the simplicity of their raising and lowering system.

Source: American Association of Oilwell Drilling Contractors, *A Primer of Oilwell Drilling,* 3rd Edition (Austin, Tex., University of Texas Petroleum Extension Service), p. 19.

Figure 15. Fixed Platform Rig and Tender on Location.

Photo: Courtesy of Santa Fe International Corporation.

Figure 16. Jack-Up Drill Barge.

After the mobile units had drilled wells which could be completed for the production of oil or gas, the wells needed individual support to protect them from the ravages of the sea. The initial wells drilled in relatively shallow water were protected by large-diameter tubular members (caissons) which were driven directly into the ocean bottom in water depths as great as 100 feet. These caissons will adequately support the well, but provide little space for the normal daily production procedures, as shown in Figure 17.

A series of floating drilling ships and barges were constructed for use in the offshore waters of California and the Gulf of Mexico and were later extended to Cook Inlet in Alaska. Most of these drilling vessels were equipped for center-well drilling operations, with the derrick located amidships and the drill pipe lowered through a hole in the center of the vessel. One such vessel has been actively engaged in the JOIDES deep-sea drilling project mentioned earlier. A few vessels were constructed with an arrangement for drilling over the side; however, these did not prove to be as much in demand as the center-well arrangement and very few are in use today. Anchoring these vessels and their abilities to orient into prevailing seas vary considerably from one floating unit to another.

The latest design in floating vessels has been the semi-submersible, as shown in Figure 18. This type of vessel can drill while its legs rest on the ocean floor in shallow water or drill in water depths as great as 600 feet while being moored. The stability of the vessel is controlled by the large legs, which provide a variable buoyancy.

b) Pollution Prevention on Drilling Rigs

Any spillage of fluids or waste disposal during drilling operations provides a source of pollution. It is necessary to take special precautions to prevent this occurrence in offshore operations. Pollution of offshore waters during

Figure 17. Caisson-Supported Oil Well.

Figure 18. Column-Supported Drilling Unit Designed to Be Semisubmersible Unit Beyond 175' Water Depth.

normal drilling operations is prevented by the installation of drip pans under the rig substructure for the collection of mud and oil from the rig floor area. These pans are drained at frequent intervals. Water-base drilling mud is not considered a pollutant.

On some offshore rigs, the sump material is gathered and treated on the platform to separate the oil products from water and non-contaminating solids. These treating units typically use chemical treatment as a means of separating the hydrocarbons for further shore processing. On drilling rigs which do not have these facilities, the waste oil products are hauled ashore to be disposed of or processed under existing regulations. Other trash from the rig is put in metal containers and transported to shore for disposal.

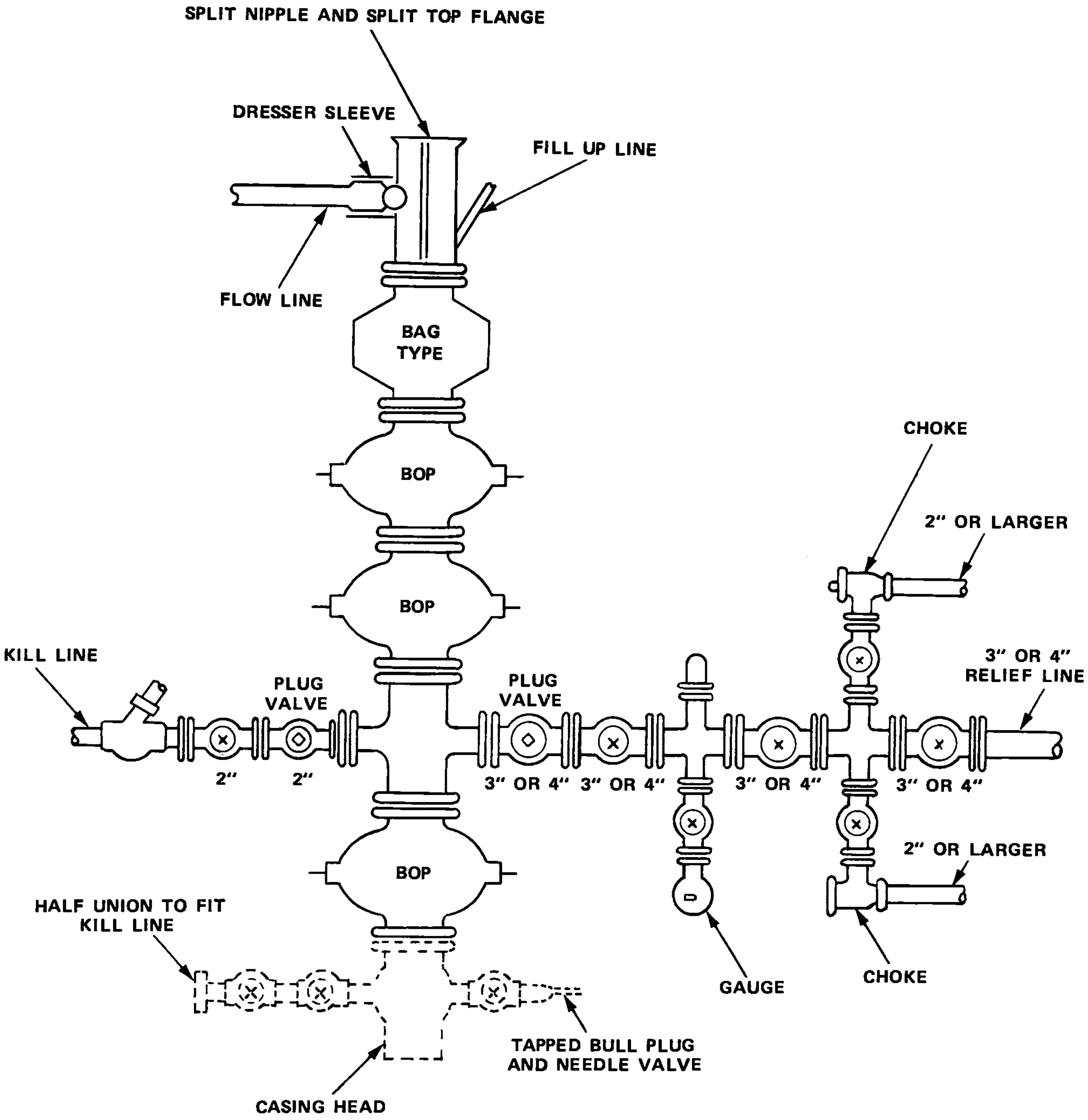
c) Well Control

The following discussion of the offshore equipment will assist in understanding those operations required for well control.

1) Blowout Preventers

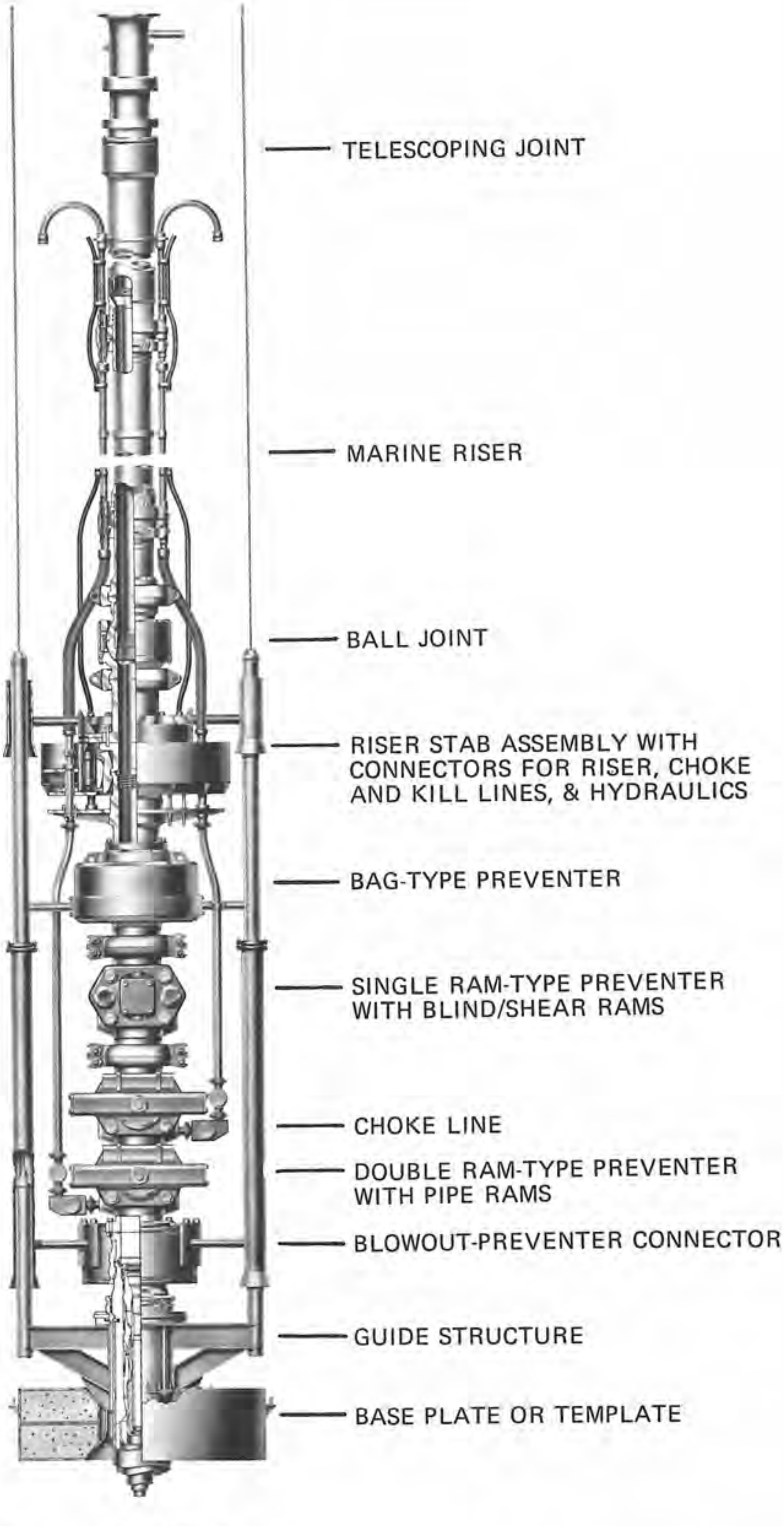
Blowout-preventer assemblies, shown in Figures 19 (conventional) and 20 (subsea), are equipped with rams and closing mechanisms designed to close around the drill pipe or around the casing, or plug the open hole.

The rubber-covered metal rams, sized to fit the drill pipe or casing being run, are called pipe rams. If pipe is out of the hole, blind rams, which are also hydraulically operated, are available to close off the entire hole. In addition, there is a rubber or bag-type preventer which is hydraulically operated to close either around the drill pipe or the entire hole.



(This schematic drawing represents the conventional blowout-preventer system and hookup. This system may be altered by the operator.

Figure 19. Conventional Blowout-Preventer Assembly.



Source: Cameron Iron Works, Inc.

Figure 20. Minimum Blowout-Preventer Requirements for Subsea Installation.

Blowout-preventers and related control equipment are tested as often as prudent operations dictate, but no less than that required by existing procedures issued by the regulatory agencies, and in each instance the equipment is approved by the appropriate agency prior to receiving a permit to drill.

Hydraulic fluid accumulators and the pumps which provide the hydraulic pressure required to operate the blowout-prevention equipment maintain a pressure capacity reserve at all times to provide for repeated operation of the hydraulic preventers. Common industry practices prescribe that a blowout-prevention drill be conducted regularly for each drilling crew to ensure that all equipment is operating and that the crews are properly trained to carry out emergency duties. All blowout-preventer tests and crew drills are recorded on the driller's log, which is a summary of the operations accomplished during his workday. The blowout-prevention equipment includes a minimum of--

- Three remotely controlled, hydraulically operated blowout-preventers with a working pressure which exceeds the maximum anticipated surface pressure, including one equipped with pipe rams, one with blind rams and one bag-type
- A drilling spool with side outlets if side outlets are not provided at the blowout-preventer body
- A choke manifold to permit control of the rate of flow of the unloading mud column
- A kill line to permit pumping into the well bore
- A fill-up line to permit filling the annulus with mud.

The blowout-prevention equipment is approved by the USGS prior to receiving a permit to drill.

When drilling from a fixed platform, conventional blowout-prevention equipment, shown in Figure 19, is located at the platform and is operated identically to an onshore situation. When drilling from a floating structure, subsea blowout-prevention equipment, shown in Figure 20, is used. The base plate of this latter equipment rests on the ocean floor and is connected to the floating vessel by a riser pipe assembly which is discussed below. The blowout preventers can be located on a jack-up barge drilling in deep water, using what is called a mud-line suspension, which involves extension of the casing to the jack-up from the ocean floor.

2) Riser-Pipe Assembly

The normal riser pipe is the assembly extending from the subsea wellhead and blowout-preventer equipment to the drilling surface (see Figure 20). The assembly has the ability to flex (ball joint) and slide to take care of any drilling vessel movement. It is this riser that completes the tie-in from the wellhead to the rig. The riser assembly, and associated drilling and completion technology, have made offshore drilling in deeper waters a practical operation.

3) Coupling Devices

Quick, positive-action, non-leak connectors (see Figure 20) tie undersea casing seats and blowout-preventer assemblies and riser pipes together. These coupling devices, which are operated without manual assistance, have contributed greatly to making offshore work practical. The connectors permit pulling the entire assembly above the base plate or just the assembly above the blowout-prevention equipment. This permits the operator to disconnect from the well during storms and to leave the well shut in with the blowout-preventers closed or to remove the entire preventer system to change size for use with a different size of drill pipe.

4) Casing

Casing, which is large-diameter pipe, is initially set to form a base for subsequent drilling operations on a well. The casing program is approved by the regulatory agencies prior to receiving a permit to drill a well. The first string of casing set is called drive pipe or structural pipe, and is either driven by large hammers to refusal by the formation or is jetted to a comparable depth using high-pressure water. This drive pipe is generally 20 inches in diameter or larger. The drive pipe is jetted if drilling is to take place from a floating vessel. The annulus is cemented to the mud line if the hole is jetted. Figure 21 is schematic, illustrating a hole completely cased.

The next casing string set is called conductor casing. It is about 16 to 20 inches in diameter and is set inside the drive pipe and extends to greater depth. Its setting depth is based on the presence of shallow hydrocarbon-bearing sands. If hydrocarbons are known to be present, it is set just above them so that drilling can be accomplished with a bag-type blowout-preventer in use when the hydrocarbon formation is drilled. If hydrocarbons are not present, based on prior wells drilled from the same platform, conductor pipe may not be required by the USGS, When conductor casing is set, it is cemented to within 40 feet of the mud line. Subsequent removal is facilitated by the lack of cement between the point of highest cement rise and the mud line.

The next casing string set is called surface casing. It is about 10.75 to 13.375 inches in diameter and is set inside the conductor casing and extends to greater depth. The setting depth of this casing is based on the depth of the freshwater sands to be protected from subsequent saltwater or hydrocarbon-bearing sands to be drilled and provide well control until another, deeper string of casing is set. Surface casing depth is also based on the fracture pressure of the formation at the bottom of the surface casing to the end that the fracture pressure is not exceeded by the mud weight required to control the formation pressures to be drilled to the next casing point. Surface casing is cemented with a quantity of cement sufficient to fill the calculated annular space to at least 1,500 feet above the casing bottom or within 200 feet below the conductor casing.

The next casing to be set is called intermediate or protection casing. It is about 7.625 to 9.625 inches in diameter and is set inside the surface casing, extending to a deeper depth. Its setting depth is based on anticipated abnormal pressure, mud weights or other well conditions. The intermediate casing is new pipe or reconditioned pipe that has been tested and inspected to verify a condition equivalent to new pipe. A quantity of cement sufficient to cover and isolate all hydrocarbon zones and to isolate normal pressure intervals from abnormal pressure intervals is used.

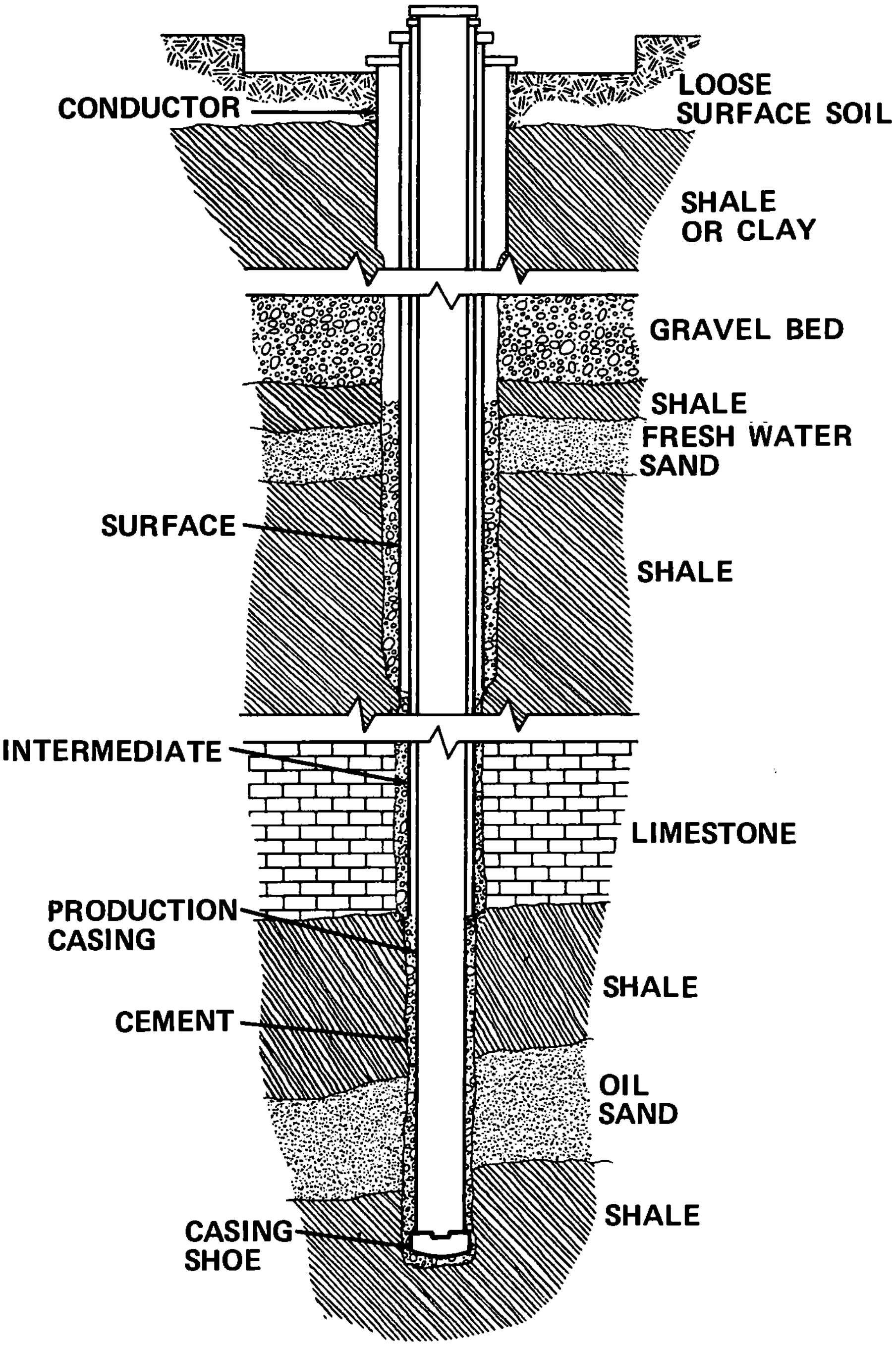
Prior to drilling the plug after cementing, a pressure test is made on all casing strings except the drive or structural casing. This pressure test will not exceed the working pressure of the casing, but must be as great as that specified in regulations. If the pressure declines more than 10 percent in 30 minutes, or if there is any other indication of a leak, the casing is recemented or repaired or an additional casing string is run, and the casing is tested again in the same manner.

After cementing any of the above strings, drilling is not begun until after sufficient time for the cement to set.

5) Drilling Mud

The drilling fluid, normally called "mud," must perform five primary functions:

- Keeping the well under control
- Bringing the cuttings to the surface
- Walling up the hole



Source: AAODC, *A Primer of Oilwell Drilling,* p. 48.

Figure 21. Casing Strings and Pipe Used in an Oil Well.

- Cooling and lubricating the bit
- Reducing friction on the drill string.

See Figure 22 for the circulation path to accomplish these functions.

Mud-testing equipment is maintained on the drilling floor at all times, and mud tests are performed at least daily, or more frequently if conditions warrant. The drilling program, which must be approved by the USGS prior to its granting a permit to drill, includes an outline of the proposed drilling mud schedule.

To bring the cuttings away from the bit, the fluid must have adequate viscosity. A certain minimum upward velocity is also required. If necessary to supply the viscosity, bentonite or other clay-like material may be added to the drilling fluid. The muds deposit a sheath of slippery mud cake on the wall of the hole. This gives the wall stability and helps prevent caving and sloughing. It also reduces friction of the drill string against the wall.

The bit may penetrate clay beds and make for excessive viscosity of the mud. This is controlled with chemical thinners, two of which are tannin extracts from trees and caustic soda or common lye.

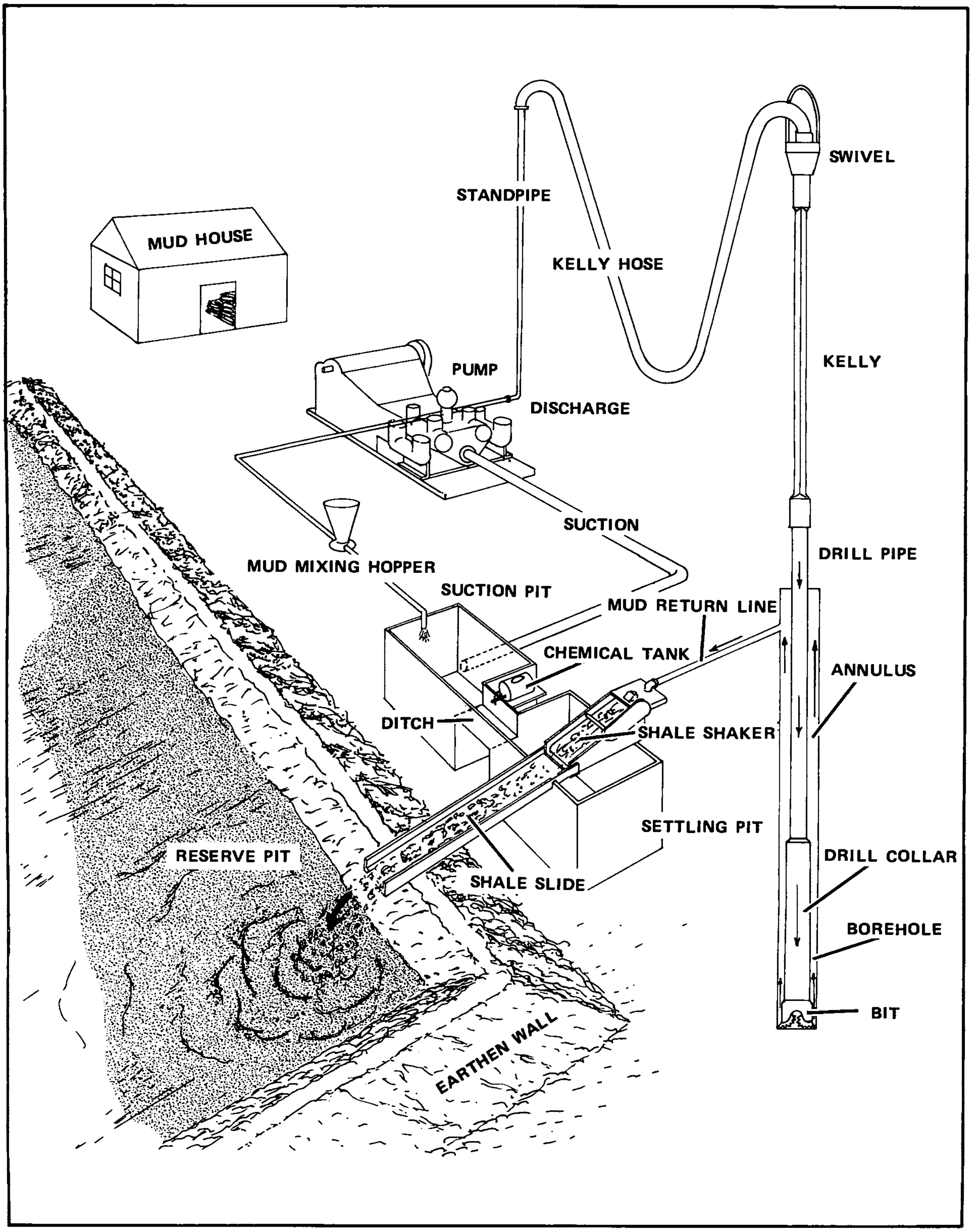
Certain porous formations may permit the water in the mud to filter out into the formations drilled through, leaving all the solids in a thick deposit or mud cake on the wall of the well. Certain commercial additives are available to control this.

Oil emulsion or oil-based muds are sometimes required to stabilize formations that swell and slough in the presence of water. The use of oil in this manner is a minor possible pollution source. All drill cuttings are treated for oil removal before their disposal, and oil-based muds are hauled to shore for disposal. As mentioned earlier, any oil spillage will be collected by drip pans under the rig. Oil substitutes for use in the mud have been developed to further minimize the risk of pollution. Normally, drilling fluids containing oil are not used to penetrate freshwater zones, so that this potential source of pollution is eliminated.

Barium sulfate (also called barite) is a very dense mineral which can be added to water and bentonite to produce a fluid weighing twice as much as water. The bentonite is needed to keep the barites in suspension in water.

Mud weight, translated to a hydrostatic head, is the principal control of pressure in formations being drilled and those previously drilled, but not cased off. If a subsurface zone is encountered that contains formation fluid at pressures exceeding that of the hydrostatic head of the drilling fluid during circulation, then the formation fluid moves into the wellbore. As formation production continues, the hydrostatic head of the drilling fluid is reduced until a situation occurs in which the well flows. If the production is gas, the uncontrolled flow of fluids is more severe than with oil or water production When a "kick" (uncontrolled flow into the wellbore) is detected, then emergency control procedures are immediately instituted. The blowout-preventers are quickly closed. The drill pipe and casing pressures are noted, and circulation of drilling fluid is started under a controlled back pressure. This back pressure is sufficient to prevent any further wellbore entry by formation fluids and allows for gas expansion without excessive bottomhole pressure. The drilling-mud weight is increased and the fluid is circulated into the hole under the controlled back pressure until the well is again restored to hydrostatic control. After control is reestablished, drilling can proceed.

In normal circumstances, loss of drilling fluid or encountering abnormally high pressure zones does not lead to a blowout. However, accidents can happen when control of the formation pressures is lost. It is these circumstances that allow a well to flow uncontrolled and permit pollution to occur. It should be stated, however, that equipment design, automation and training programs all are used to prevent loss of well control.



Source: AAODC, *A Primer of Oilwell Drilling*, p. 31.

Figure 22. Rotary Rig Fluid Circulation and Mud Treating System.

A highly porous or previously fractured formation encountered while drilling can cause loss of drilling mud to that zone. The loss of drilling fluid to a fractured zone reduces the hydrostatic head in a wellbore, allowing for flow into the wellbore from other formations. If the exposed formations contain oil and/or gas and the well cannot be shut in at the surface or cannot be controlled, a severe pollution problem could exist. In normal situations, the loss of drilling mud to the formations is shut off with plugging material. When lost circulation is controlled, drilling operations can proceed. In some cases, it is necessary to seal the fractured or highly porous zone with cement pumped in at a high pressure. In the event formation fluids are allowed to flow to the surface, they must be controlled, collected, treated and stored to prevent pollution.

Valves to fit all sizes of drill pipe in the hole are available on the drilling rig floor to shut in the drill pipe if back flow occurs during a trip of the drill pipe in or out of the hole. A valve called a "Kelly Cock" is located at the top of the drill string, immediately below the swivel, and can be closed to stop back flow if it occurs while drilling.

d) Blowouts

The greatest potential for pollution of offshore waters by hydrocarbons during drilling operations is from a blowout. This is a relatively rare occurrence because of the equipment and techniques developed by the petroleum industry to prevent them, as previously described. Once the hydrostatic head required to control formation pressures is inadequate, feed-in from the formations may commence. This loss of pressure may result from either drilling into an unanticipated high-pressure formation or the loss of a hydrostatic balance because of a zone's accepting the drilling fluid.

1) Alarm Devices

Many preventive devices have been developed and are in regular use to alert the drilling crew to a potential blowout condition. The following typical mud system monitoring equipment is installed with derrick floor indicators while drilling operations are taking place:

- Recording mud pit-level indicators to determine mud pit volume gains and losses and including visual or audio warning devices
- Mud volume measuring devices for accurately determining mud volumes required to fill a hole on trips in and out of the hole with the drill pipe
- A mud flow rate indicator to determine that flow rates essentially equal the circulating pump discharge rate.

Before starting out of the hole with the drill pipe, the mud is circulated with the drill pipe just off the bottom until the mud is properly conditioned to its designed characteristics. When coming out of the hole with the drill pipe, the annulus is filled with mud before the mud level in the hole drops below 100 feet. The volume of mud required to fill the hole is observed and, any time there is an indication of swabbing or influx of formation fluids, the drill pipe is returned to the bottom and the mud is conditioned again.

2) Control of Threatened Blowouts

The principal means of preventing threatened blowouts has always been sufficient hydrostatic pressure, but when used to excess the results are a low drilling rate, lost circulation and wall sticking of drill pipe. An increasing understanding of the occurrence of abnormal pressures has allowed use of low mud densities prior to penetrating the high-pressure section where casing can be set. Mud density can then be increased as required.

However, drilling into the high-pressure zones unexpectedly and with insufficient mud weight can result in lost time, stuck drill pipe or, in extreme instances, uncontrolled blowouts which must then be brought back under control. Considerable effort is expended to train crews in systematic prevention of threatened blowouts. The practice of closing in a "kicking" well, in order to read the drill pipe pressure, and to add the hydrostatic pressure of the uncontaminated drill-pipe mud column to determine required bottom pressure and mud density, has become common. Establishing a constant circulating rate with the initial choke-maintained back pressure equal to the close-in annular pressure starts the well-control operation.

The majority of blowouts occur when pulling and running the pipe. Increased attention to hole filling and use of recording pit-level indicators has been helpful in determining that the hole is taking an amount of mud equal to the pipe volume withdrawn. This, by industry experience, is the most important item in blowout prevention.

2. Well Completion

a) Formation Evaluation and Well Testing

After a well has been drilled to the desired total depth, it must then be completed as an oil- or gas-producing well, or plugged with cement as a dry hole and abandoned. Exploratory wells require geological evaulation of the formations penetrated and extensive testing to determine their potential commercial value prior to completion. Development wells are drilled to develop the reservoirs discovered by the exploratory wells. As a general rule, they require a minimum amount of evaluation work.

Exploratory wells drilled in shallow waters may be completed by utilizing caissons or small bracing structures similar to those used onshore and in inland waters (see Figure 17). Exploratory wells drilled from platforms are completed in a manner similar to development wells which will be covered later.

On exploratory wells drilled in deeper water depths from floating vessels, it may be necessary to "suspend operations," i.e., leave the well in such condition that it may be reentered and completed as a producer or abandoned readily. The decision to complete or abandon in many cases must be deferred until other wells are drilled to determine if the field has sufficient reserves and productive capacity to justify the investment necessary to install production facilities.

Field development wells in deeper water are normally drilled from platforms. They often require little testing, and are completed after determining the exact location of the producing horizon.

The evaluation of the offshore well to determine its commercial potential may be done in several ways and does not differ from onshore operations. The bit cuttings collected during drilling are examined by geologists to determine the characteristics of the formations and their contained fluids.

Various types of special tools, run in the well on multi-conductor wireline, are placed in a well to study and evaluate the formation. Hydrocarbon content and porous nature of the formation being evaluated, hole size and formation lithology are determined by these devices. Several different types of tools are used to measure the producing capabilities of a well. The "log" of the well, as such measurements of producing capability are called, may be obtained by running tools, some of which individually measure the depth, electrical conductivity, radioactivity and acoustic characteristics of the formations drilled through.

The most accurate diagnostic method of evaluation is a "drill stem test" which involves the production of formation fluid to the surface through pipe. This information, combined with an analysis of bottomhole pressure, permits an estimate of the quantity of fluids that the formation can produce as well as the type of fluid.

To prevent pollution of the ocean, the fluids that are produced during a drill stem test are collected in tanks at the surface. These fluids are recovered by flowing to the surface, by being displaced from the well with drilling fluid, or by collecting them in a chamber placed on the bottom of the drill pipe. The oil, water, drilling mud and gas are produced from the well and are passed through a separator. The drilling mud is returned to the drilling-fluid tank, the oil not used for laboratory analysis is placed in a waste-oil tank, and the gas other than that collected for analysis is burned by an appropriate flare arrangement.

b) Setting the Production Casing

After testing is concluded and it has been determined that the drilled well is to be completed as a producing or fluid-injection well, or that operations are to be suspended, the final string of casing is placed in the well and sealed to the penetrated formation with cement. Blowout-preventers attached to a previously installed casing string during drilling operations guarantee control of the well during completion operations. Location and operation of these preventers have been previously discussed under drilling operations.

The casing is cemented, employing the same techniques that are used onshore, as shown in Figure 23. This may include the use of centralizers and wall-cleaning devices and pipe movement to improve displacement of mud and placement of cement in the annulus between the pipe and the hole. Proper placement of cement in the hole casing annulus is necessary for prevention of interzonal flow between oil, gas, or saltwater or freshwater sands. Regulations specify that cement around the production casing extends up a sufficient distance to protect all potentially productive zones. If the distances are not too great, the cement may extend up and into the next-larger casing string. This seal prevents leakage between multiple casing strings set in a well.

Drilling mud displaced by the casing and cement is returned to the mud tanks. Mud contaminated by cement is disposed of in waste tanks provided.

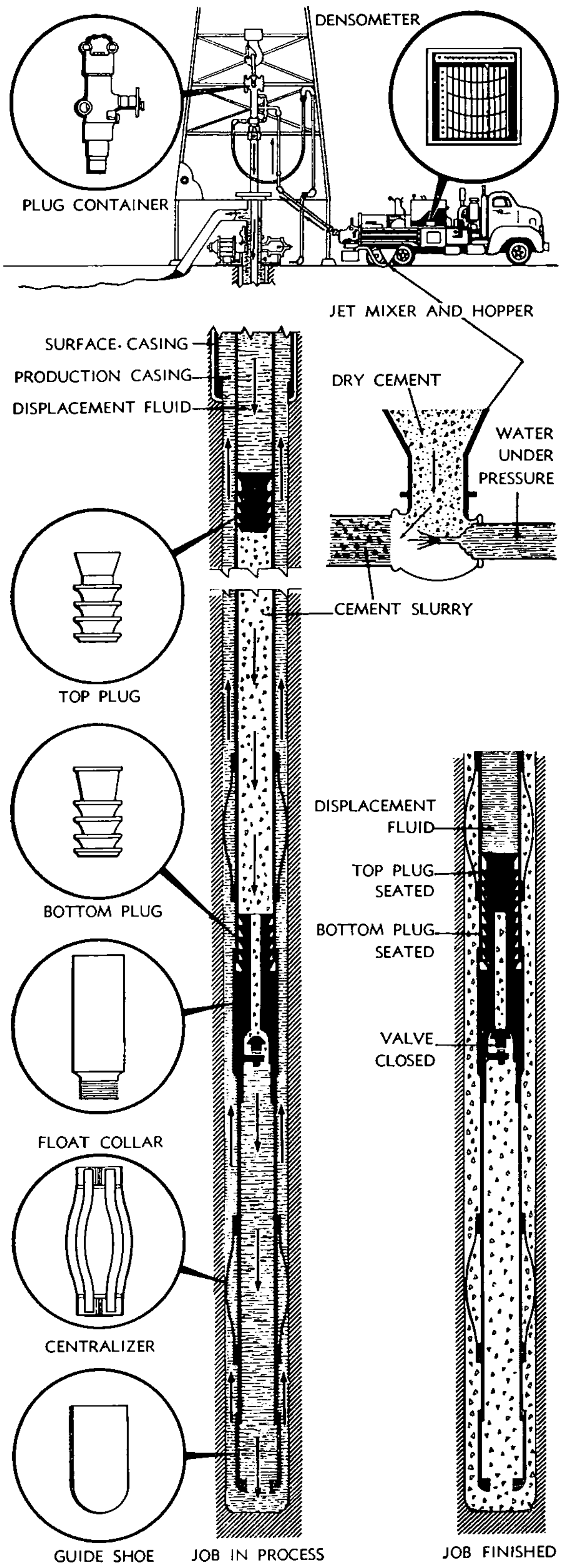
c) Running Tubing and Setting the Christmas Tree

After the cement has had sufficient time to harden and has gained adequate strength, which is predetermined from laboratory tests conducted under simulated well conditions and specified in applicable regulations, the casing is pressure tested and any cement remaining in the pipe is removed, if necessary, by conventional drilling procedures.

To ensure adequate control of well production and to permit future maintenance of the system, well fluids are normally produced through a relatively small diameter tubing installed inside the production casing. Under certain well conditions, two or even more parallel strings of tubing may be necessary. One such situation would be if two or more productive horizons are to be produced simultaneously but as separate completions. Another would be when well pressures or the corrosive nature of well fluids make it desirable to provide a "kill string." A third would be to provide additional deliverability without undue pressure drop due to friction.

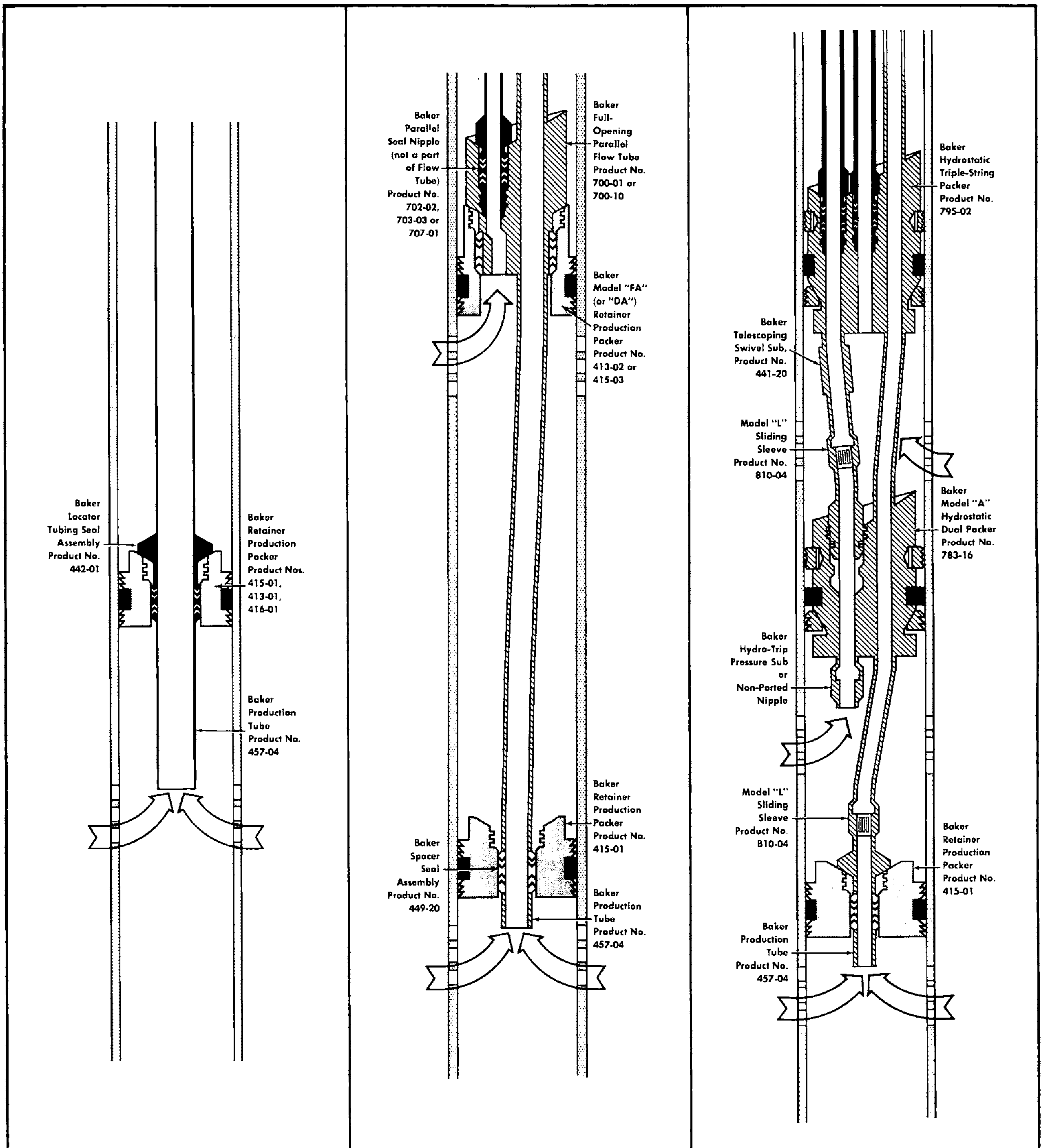
The tubing strings are run and set on a tubing hangar located at the top of the casing string. The tubing hangar suspends the tubing strings. Packers are used to seal off the casing-tubing annulus and are placed near the bottom of the tubing string. They are also used in multiple completions as shown in Figure 24. The tubing strings, related equipment, and the packers are pressure tested to determine that there are no leaks in the subsurface production system. The tubing strings are then sealed with retrievable plugs placed in the tubing. These plugs seal the well so that the blowout-preventers can be removed without danger of opening the well to uncontrolled flow.

The "Christmas tree" (or surface control valve), as shown in Figure 25, is normally installed at the surface. Surface installation on a fixed platform involves the use of a conventional land-type control tree employing the same



Source: AAODC, *A Primer of Oilwell Drilling,* p. 63.

Figure 23. Diagram of a Casing Cementing Job.



Packer set in casing with Locator Tubing Seat Assembly and Production Tube installed for single-zone production. Also the basic hookup for permanent completions.

Parallel string installation using two Retainer Production Packers. Each zone is confined to its individual tubing string. Full-opening to lower zone permits use of permanent-type completion tools.

Producing three zones, each through its own tubing string. Well may be flanged up before the retrievable packers are set. For a completely retrievable hookup, a Baker Hydrostatic Single-String Packer may be substituted for the lower packer.

Source: *Composite Catalog of Oil Field Equipment & Services* (Houston, Tex., World Oil, Gulf Publishing Co., 1969), pp. 514, 517, 520.

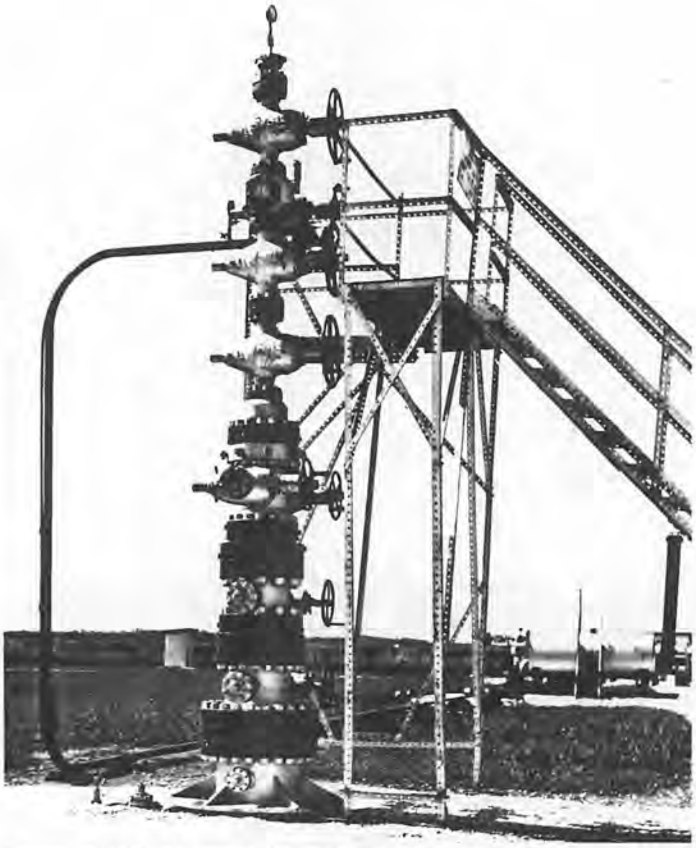
Figure 24. Setting Tubing for One to Three Production Zones.

procedure as is used on land. A flowline is provided to convey produced fluid to the surface production and storage facilities.

A limited number of completions have been attempted using an underwater Christmas tree of the type shown in Figure 26, which is installed on the ocean floor. Such completions are still experimental, but represent steps taken by the industry to improve and advance techniques. This well-control device has to perform the same functions as onshore equipment and, in addition, meet the requirements imposed by a remote underwater environment. While subsea completions are feasible and will probably increase in the future, the technology is still in its infancy. The history of subsea completions is too short to compare the pollution risks associated with them with those of platforms. Should a completion of this nature result in a blowout, normal surface control procedures, such as capping the well, could not be accomplished.

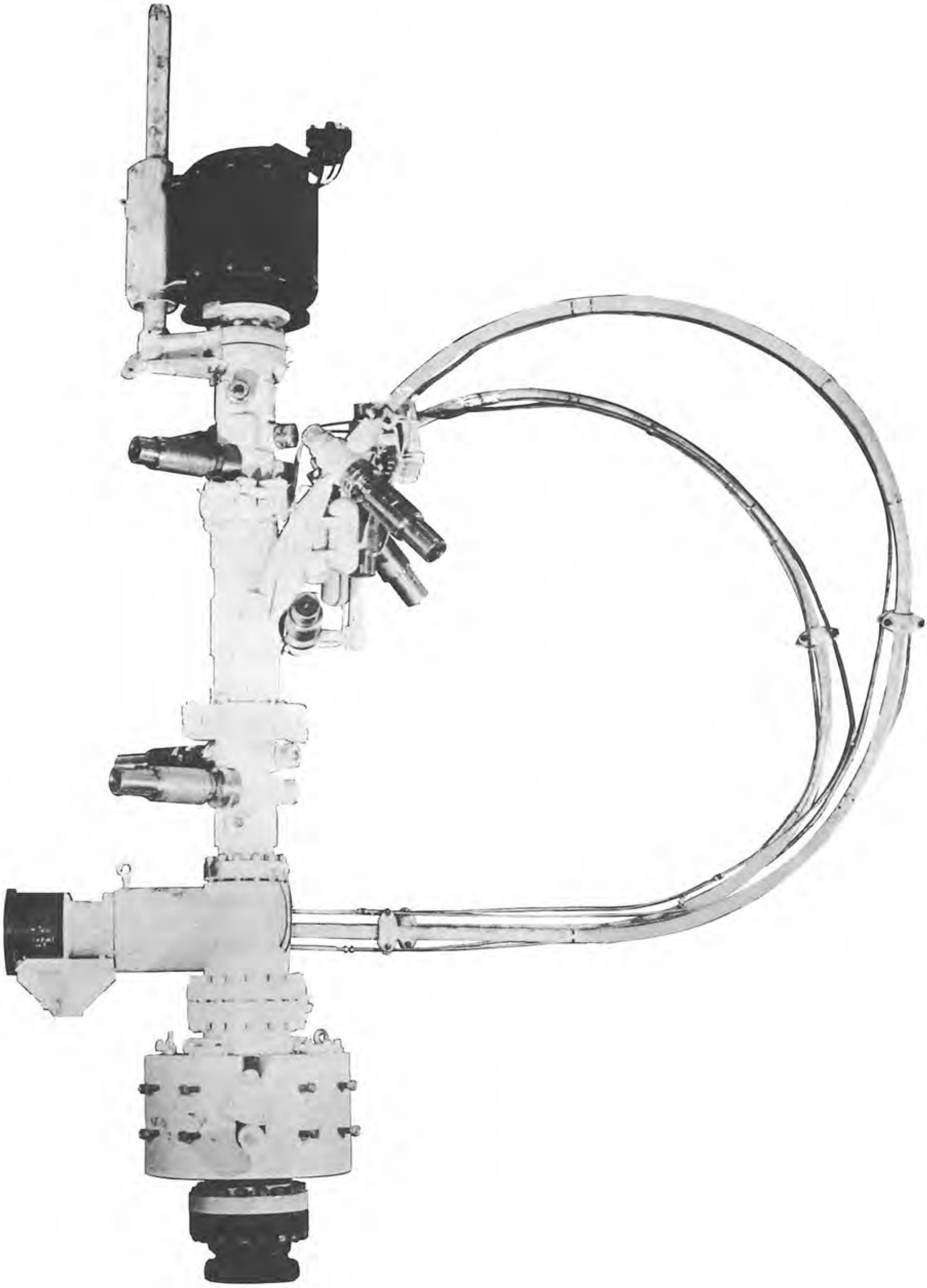
A safety valve is generally installed in the tubing through which oil or gas is produced. This is required in all wells located on the Outer Continental Shelf unless exceptions are obtained for specific circumstances listed in the regulations. State regulations include similar requirements in coastal waters under state jurisdiction. The conditions which merit exceptions are those which otherwise would make well operation impractical. Regulations provide for the installation of safety valves in all wells not so equipped when storms threaten. This requirement is tempered to the availability and safety of men and equipment to make the installations.

There are two broad types of subsurface safety valves in general use today. The most used type has the sealing element--a flapper, dart or ball--held open by a spring and/or a pressured bellows. When the fluid flow through the valve exceeds a preset rate, the pressure drop developed across the valve will automatically overcome the spring and close the valve, shutting in the well at



Source: AAODC, *A Primer of Oilwell Drilling*, p. 69.

Figure 25. Completed Well Showing Control Valves on "Christmas Tree."



Source: Cameron Iron Works, Inc.

Figure 26. A "Christmas Tree" for Underwater Installation.

least 1,000 feet below any damaged wellhead equipment. The other, more versatile subsurface valve has the sealing element held open by hydraulic pressure applied from the surface through an auxiliary conduit. The surface hydraulic pressure control can be rigged to close the subsurface valve when disastrous conditions of wild well flow, overpressure, low pressure and/or fire are sensed in the wellhead equipment. The hydraulically controlled valve, however, is difficult to install more than a few hundred feet below the wellhead.

d) Perforating Casing

It is a common practice to run tubing and set the Christmas tree, then displace the drilling mud in the casing with water or oil. Casing perforations are then made below the tubing by use of a small-diameter gun run through the tubing on an electric cable. The cable is run through a sealing device (lubricator) extending above the tree to keep the well under control at all times.

This procedure often permits the use of fluid in the wellbore with a light enough weight to exert a hydrostatic head less than the pressure in the zone perforated. This permits the well to be produced immediately, if desired.

Another completion procedure is to perforate the casing before tubing is run and the tree is set. This requires keeping a fluid in the well which will overbalance the formation pressure. This fluid is displaced after the tubing is run and tree set.

In some cases, natural flow cannot be established without artificially removing some fluid from the well. This may be done by pumping or gas lift or by swabbing part of the fluid from the tubing thereby lowering the hydrostatic head on the producing formation.

Fluids produced during completion are collected in tanks in much the same manner as those produced during testing or during normal producing operations which follow completion.

e) Suspension and Abandonment

The fact that it is sometimes necessary to suspend operations on a well pending additional drilling has been mentioned earlier. The additional drilling must prove that there are sufficient reserves and adequate producing capacity to justify the investment in permanent production facilities. Such wells must be left in condition to reenter them for completion or to be abandoned readily if the reserves are noncommercial.

Where operations are to be suspended, production casing will be set and testing may be done through the casing. Plugs are set above the casing perforation, made opposite the productive formations, to confine fluids to formations. Generally, mechanical plugs are capped with cement to assure additional seal. In addition, a cement plug is set in the production casing at the mud line to facilitate abandonment, if necessary. The wellhead is capped rather than being equipped with a Christmas tree.

After operations are suspended, and if commercial reserves are found to exist, the well can be reentered. The casing is extended to the production platform which has been provided and completion effected in the usual manner after drilling out the previously set plugs.

If the reserves are found to be noncommercial, however, the well is abandoned by shooting off the casing at the mud line, above the top plug. The other plugs, set above the casing perforation, confine the formation fluids.

When testing fails to indicate the presence of commercially producible oil or gas in a well, it is often abandoned without the final string of casing being set. It is necessary to seal the formation in such a manner that there will be no flow of fluids from one permeable zone to another. This is done by proper placement of cement plugs and the use of drilling mud between the plugs. Regulations specify the minimum length and location of plugs to be set. Approval of the abandonment procedure for each well must be obtained from the USGS. Plugs are required to isolate potentially productive zones and at the top of the uncased hole extending into the longest string of casing. If all freshwater zones have not been cased off, cement plugs are set through them and up inside the casing. A top plug is set and casing shot off at the mud line. During plugging operations, the danger of blowout is no greater than during drilling, since all control equipment remains in use.

3. Production

Production is basic to the oil industry. Although this phase is less spectacular than the drilling phase, it generally covers a much longer period in the history of a producing field.

Space limitations for offshore operations present a critical problem. It is not uncommon to use a separate structure from the well structure to contain producing equipment. Such a plan is illustrated by Figure 27. Water depth and other factors which influence cost of offshore structures limit the use of this technique.

In some instances it is necessary to defer the installation of all or part of the producing facilities until the drilling phase has been completed and drilling equipment is removed from the offshore structures.

A great deal of reliance is normally placed on pipeline deliveries of offshore oil to onshore installations. This has the advantage, over the use of barges for transporting oil, of minimizing storage on the offshore structure. The reduction in the hazard of pollution by this procedure is obvious. Stored oil is also a potential fire hazard in addition to the pollution hazard.

From the earliest history of offshore operations, safety of personnel and equipment has been given a very high priority. Pollution hazards have received increasing emphasis in recent years, and those features developed to maintain full control and safety of wells and production also contribute to pollution prevention. The greatest hazard of pollution is human failure, as is true for other safety problems. In eliminating this hazard, the industry has endeavored to provide completely automatic safety shutdown devices which control production as near the source as is practical. The safety valves located on individual wells, either surface or subsurface, are the basic control. The usefulness of these mechanical means is supplemented by extensive safety training of operating personnel.

a) Well Equipment

Fundamental well equipment such as casing, tubing, and surface and subsurface valves are normally installed during the drilling and completion processes. Planning for the production phase of the operation guides such equipment installation. In many instances, wells flow over a considerable portion of the producing life, but in some cases artificial lift early in the field life is required. Three basic artificial-lift systems are considered practical for offshore operations. Gas lift is common, and subsurface hydraulically operated pumps are used frequently. A third method is subsurface electrical pumps. Each of these methods of artificial lift dictates slightly different well equipment, and the initial installation is normally planned to conform to this need.

A comprehensive plan for safely handling well production is essential to orderly operation of an offshore facility. Petroleum is almost universally associated with hydrocarbon gas which is in solution in the oil at reservoir pressure, but the gas becomes a separate phase in flow lines and tubing as pressure is reduced. Produced formation water associated with the oil and gas is common. Offshore separation of gas and oil is the general practice, although delivery to shore for separation is a possibility. Surface lines between the well and platform separation facilities must be designed to

Photo: Courtesy of Sinclair Oil Corporation.

Figure 27. Modern Offshore Oil-Drilling Platform (Alaska's Cook Inlet).

accommodate the two- or three-phase flow. It may be necessary to handle all three phases under relatively high pressure until the multiphase flow reaches separation equipment, with the systems used accommodating pressure equal to maximum wellhead pressures.

Piping on offshore structures, as well as that for similar installations onshore, is relatively complex, because it is necessary to provide for testing individual wells without interrupting normal production from other wells. This requires manifolding to permit diverting individual wells into either the test separator or the production separator. In cases where different types of production occur, a third flow system may be essential to keep production separate. For example, certain wells may produce water-free oil, while other wells on the same structure produce oil that must be cleaned of its water content. If all production should be commingled in a single line, then all production would be subject to the cleaning process. It may be necessary to keep gas-well production separate from oil production.

Safety features incorporated in the flow and test manifold system normally provide for shut-in of the wells for a number of malfunctions such as high and low pressure on the flow line or high liquid level in one of the separators. Shut-in controls may be actuated manually from a central control station or may be actuated automatically by a fire or other disaster.

After the produced fluids have been separated into the three basic components--gas, oil and water--they may be handled separately on the offshore structure. The gas usually constitutes the greatest hazard to safety, although it is less of a pollution problem than oil or water which may contain traces of oil. Most separators permit liquid particles to be carried over into the gas stream, and special scrubbers designed to remove this liquid must be installed before the gas can be vented, since any liquid carried to the vent may be a source of water pollution. If the gas is to be marketed or used for fuel, it may be necessary to clean and dehydrate it. This is also advisable for gas that may be compressed for gas lift. The water from a conventional separator sometimes contains minute particles of oil which preclude its release to offshore waters without further cleaning. Because of space limitations, it is sometimes more practical to deliver the oil and water to an onshore facility for processing than to clean the water for release offshore.

In recent years, special filter media coalescers have been developed that offer promise for cleaning produced water offshore. Various cleaning devices have been used, including a flotation cell that releases very fine air or gas bubbles into the water, which lift the oil particles to the surface for skimming. In some instances, adequate cleaning of separated water can be obtained by storage for several hours in a conventional tank to permit gravity separation of the oil and water. This may not be possible because of limited space offshore.

In the event that oil and water are commingled and delivered by pipeline to an onshore station, conventional cleaning and dehydration facilities are utilized.[216] Cleaning the water for release into the ocean is common at onshore facilities. Brines produced along with oil are almost never considered pollutants when only traces of oil remain in the brine.

On multiple-well platforms which are connected to a pipeline, a system called "Lease Automatic Custody Transfer" (LACT) is employed to transfer the crude oil from the on-platform separator or tanks to the oil pipeline. The term *Lease Automatic Custody Transfer* refers to the selling of oil from a lease to the crude oil purchaser on an unattended, automatic basis. The system automatically and accurately determines the quantity and quality of oil being delivered to the pipeline. A typical LACT unit is shown in Figure 28. The supervision and control of the various automatic systems may be accomplished from a remote-control point, normally onshore, and generally through the use of telemetering or radio system. Obviously, cleaning and dehydration must be done on the platform if marketable oil is delivered to pipeline and, therefore, water released into the ocean must be cleaned in compliance with regulatory agency standards.

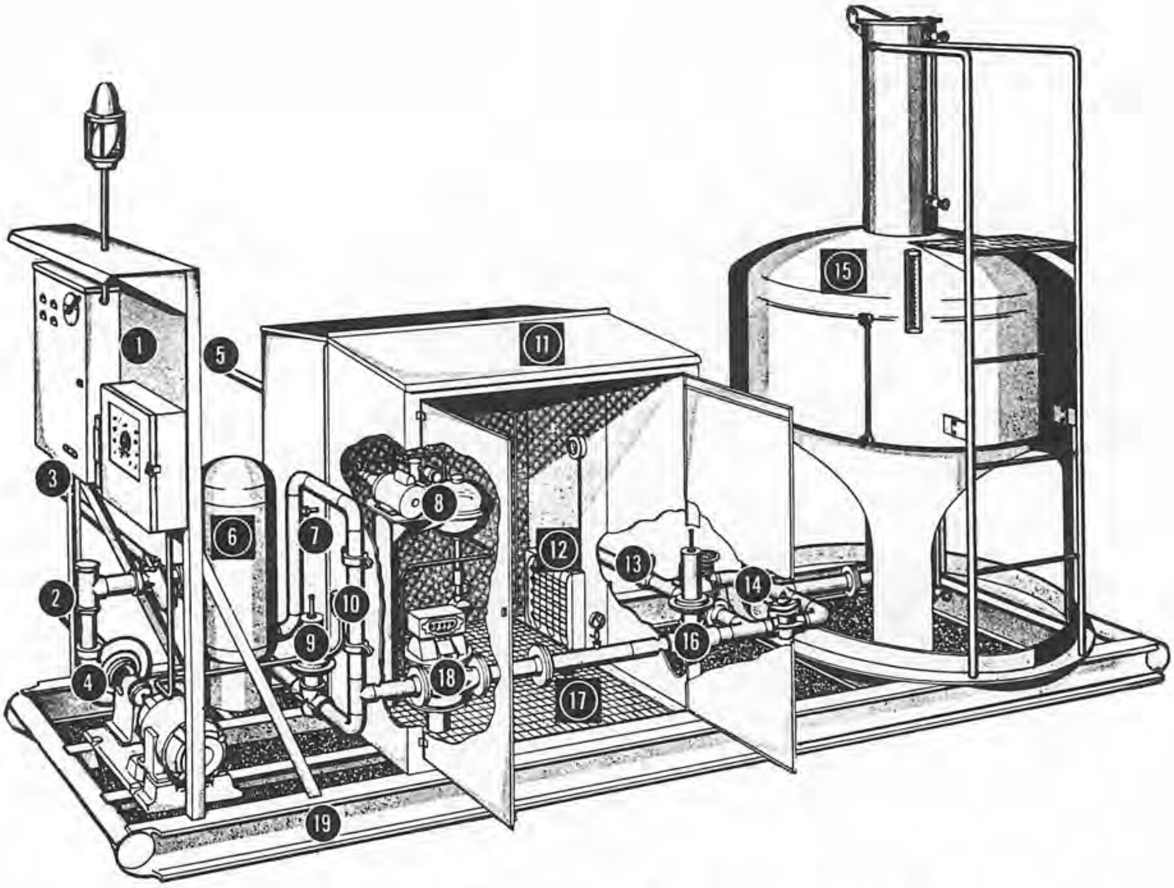
In areas where gas is available, a system referred to as "gas lift" can be used to lift the oil to the surface. Basically, this system consists of injecting high-pressure gas through a series of pressure-actuated valves into the annular area between the well casing and production tubing and emitting gas at selected elevations, aerating the liquids and lightening their weight so they may more readily be recovered. A multiple-valve gas lift installation of this type is shown schematically in the NPC Technology report.[217]

Bottomhole pumps may also be actuated by high-pressure hydraulic fluid pumped into the well through special tubing. This system of pumping is described in the Technology report.[218] The problems associated with such an installation offshore are discussed in a paper presented at the Second Offshore Technology Conference in April 1970.[219]

Electrically powered, bottomhole centrifugal pumps are also applicable where an ample power source is available. This equipment is also described in the Technology report.[220]

b) Inspection, Maintenance and Repair

Periodic inspection of all production equipment is essential if reliable operation is to be expected. The system followed onshore is applicable in most areas. Ultrasonic inspection of piping and pressure vessels provides evidence of either corrosion or erosion. Safety drills and operational checks are desirable to verify that all safety devices are functioning. All personnel must be trained to remedy any situation that may cause or contribute to pollution, and to report at once to the next-higher authority any situation which cannot be corrected immediately. Regulations also require immediate reporting to



① Skid mounted control back with control panel, B S & W Monitor, power transformer and rotating beacon.

② LACT inlet.

③ Rejected oil outlet.

④ Transfer pump and motor.

⑤ Pipeline delivery.

$\boxed{6}$ Air Eliminator.

⑦ Sample probe.

⑧ Sampler with container.

⑨ Combination bad oil back pressure valve.

$\boxed{\bigcirc}$ Indicates optional equipment. Other components furnished in basic LACT unit.

⑩ Monitor probe.

$\boxed{11}$ Galvanized meter house.

$\boxed{12}$ Electric thermostat and explosion-proof heater.

⑬ Pipeline check valve.

⑭ Meter prover loop with double sealing gate valve in main line.

$\boxed{15}$ API meter prover.

⑯ Combination good oil and back pressure valve.

$\boxed{17}$ Skid-proof flooring.

⑱ PD meter with automatic temperature compensation & counter-printer.

⑲ 6" I beam skids.

Source: NPC, *A Study of Offshore Oil Pollution During the Exploration and Exploitation Phases.*

Figure 28. LACT Unit.

appropriate agencies of any significant oil spill. (The recently adopted regulations USGS OCS 8 and 9 contain additional requirements for inspection, maintenance and repair.)

Inspection, maintenance and repair of all subsurface safety valves are required by regulations at specified intervals. The personnel associated with offshore operations are generally well trained, but replacements are employed from time to time. Training, together with on-the-job experience, provides personnel competent to conduct offshore operations and therefore is a continuing essential requirement. Assistance from schools and local organizations in training personnel for oil-industry offshore work is helpful, but actual experience on the job is necessary to ensure competency. To operators offshore, this training is most valuable for pollution control.

c) Control of Corrosion

Corrosiveness of the produced well fluids sometimes presents a serious problem in the destruction or failure of well tubing, flow lines or pressure vessels. In instances where the corrosiveness is a serious operating problem, considerable damage to well tubular goods may be expected. The corrosion problem may arise due to hydrogen sulfide, carbon dioxide, organic acids and other eletrochemical sources. To counter this problem, the same procedure used on shore locations is employed; i.e., typically, internally coated tubing may be placed in the well, the tubing-casing annulus filled with a non-corrosive liquid and corrosion inhibitors injected into the well.

Surface equipment which handles brines is subject to severe corrosion if significant oxygen is present in the water. For water-injection facilities used to improve oil recovery, it is usually desirable to remove all oxygen from the water or to use water of low oxygen content. A major part of the oxygen may be removed by gas stripping and the remaining oxygen treated out with chemical agents. All piping and equipment which handle untreated water must be protected by internal coating, special corrosion-resistant metallurgy inhibitors, or a combination of these means.

In general, there is little direct danger of pollution resulting from corrosion of water-handling facilities, but indirectly, any loss of control endangers the entire facility. From this standpoint, corrosion protection of the structure in its entirety must be carefully supervised. To counteract corrosion of the platforms themselves from the saltwater environment, operators may use cathodic protection equipment consisting of sacrificial material (anodes) that is corroded in preference to the platform, or a system that imposes an impressed electrical current on the exposed metal.

d) Repair and Recompletion

After an offshore well has been on production for a period of time, it is frequently necessary to conduct remedial work. These operations may include repair of subsurface equipment; treatment of the formation to increase productivity; change of completion interval to reduce water or gas production; cleanout of accumulated mud, silt, scale or paraffins to improve productivity; control of the influx of formation sand; and reperforating to open more effective pay to the wellbore. It may also be necessary to recomplete the well in another zone after the initial productive zones are depleted.

Remedial operations and recompletion of wells on fixed platforms are carried out in a manner similar to that used onshore. In general, pollution hazards during workover operations are comparable to those experienced during drilling, and careful planning is necessary to ensure that a well is under control at all times. The normal procedure calls for "killing" the well with mud or other suitable fluid. Workovers sometimes are performed with oil or oil-base mud as the kill fluid, since it is less likely to damage the permeability of the producing formation. In common use today is a treated salt water which can be weighted and will not damage the formations. In addition, this fluid is safer from a pollution standpoint. Also, partially depleted formations frequently have reduced pressures and require control with a lighter wellbore fluid than that used on initial completion. Any spills of oil or oil-base mud are a potential pollution hazard, but are not ordinarily a problem if all drains to the collection and treating tank are maintained at maximum efficiency.

1) Well Stimulation

Acidizing, or pumping acid into a carbonate or sand formation, and hydraulically fracturing a productive interval account for more than 80 percent of all the well-stimulation treatments.[221] Therefore, the discussion of this topic will be limited to these methods.

Acidizing may be divided into two broad categories: matrix acidizing and acidizing of the formation through fracturing.

Matrix acidizing treats the formation around the borehole to improve productivity or injectivity by removing scale or by increasing the permeability of the rock adjacent to the well. This is a widely used stimulation technique in offshore wells, which usually involves pumping several hundred gallons of plain hydrochloric acid, organic acids or hydrofluoric acid at a low rate and pressure into the producing formation. The acid is pumped down the existing tubing string in the well, using formation crude oil to displace it to bottom. After treatment, the well is placed back on production and the spent acid, which is neutralized by salt water, is separated from the crude oil and disposed of in the same manner as the salt water produced from the well. In wells where the bottomhole pressure is low, gaseous nitrogen or carbon dioxide is introduced with the acid to assist in its removal of spent acid from the well.

Fracture acidizing is generally conducted in rock formations containing carbonates, and is conducted by pumping acid into the well at high injection rates to produce deeply penetrating fracture or flow channels in the formation. Tens of thousands of gallons of acids are typically used in a treatment of this type.

The acid contains an inhibitor to minimize corrosion of metal and may also contain other surfactants to prevent the formation of emulsions with the oil. It is preferable to pump the acid down the existing tubing strings to eliminate the necessity of removing the tubing and packers and killing the well by filling it with mud or salt water, gaseous nitrogen, or carbon dioxide. The spent-acid water produced to the surface can usually be dumped into the ocean after after all oil has been removed. All oil and oil-contaminated salt water are placed in tanks for onshore disposal.

Hydraulic fracturing is a method of stimulating a well by rupturing the formation with hydraulic pressure and placing a propping agent, such as sand, in the fracture to prevent it from closing after the pressure is released. This technique produces a deeply penetrating flow channel in the pay formation which greatly increases well productivity or injectivity. Fracturing has not been used as extensively in offshore wells as has acidizing.

It is not usually necessary to "kill" the well before treatment with either of these two methods. The fracturing fluid and the oil or saltwater flush fluids are pumped down the tubing strings after removing all plugs. If the well can be returned to flowing status after treatment, the fracturing and displacing fluids are passed through fluid separators and oil skimmers to remove all oil. The treated salt water is returned to the ocean and the oil is pumped into the flow lines or tanks on the offshore platform.

2) Sand Production

In some areas, the influx of formation sand into the wellbore presents a major obstacle to production. Several methods are available for use in repairing wells to overcome this problem, but the most widely used are sand-consolidating plastics and gravel-packed wire screens. Gravel packing is the most successful method used, but it is also more difficult to apply than are consolidating plastics.

All methods of controlling sand influx require that all of the sand be cleaned from the wellbore after the well "sands up" and goes off production. This sand normally is oil saturated and must be cleaned or transported ashore to avoid the danger of pollution of offshore waters.

Gravel packing involves installing a wire-wrapped, slotted liner screen on the drill string, placing it on bottom, and circulating gravel (which is usually the size of coarse sand) around the liner and out into the perforations connecting the wellbore with the productive formation. Gravel acts as a filtering medium that restrains the formation sand and prevents its movement into the well. A typical gravel pack is shown in Figure 29.

Sand consolidation with plastic is conducted by injecting a liquid plastic such as a phenolic, an epoxy or urethanes into the formation to bind the sand grains together yet leave the productive interval permeable to the flow of fluids. The plastics are usually preceded and followed by special solutions to clean the formation sand and to remove the excess plastic. No special downhole tools are required other than casing packers and plugs separating the different treating solutions and displacement fluid. Therefore, this method requires less well manipulation and is less costly than gravel packing, but it also less successful.

Squeeze cementing (displacing cement into a well under high pressure) is often required to repair faulty cement which permits communication between zones. Squeeze cementing is also used to seal off a depleted zone prior to recompleting a well in another producing horizon. Casing leaks are also repaired by this method. At the completion of a remedial job, excess cement and drilling fluids are reversed out of the well and circulated to the ocean where they quickly settle to the bottom. The cement is relatively inert and is not a pollution hazard. All squeeze-cementing operations are carried out at pressures below the safe working pressure of the tubular goods involved.

3) Recompletion

After the producing zone in a well has ceased to produce at economic rates and further stimulation is not possible, the well is often recompleted in another producing horizon. The depleted zone is sealed off and the new zone opened for production. The recompleted zone requires formation testing and evaluation. It may also be necessary to stimulate these new zones, using either the acidizing or fracturing technique.

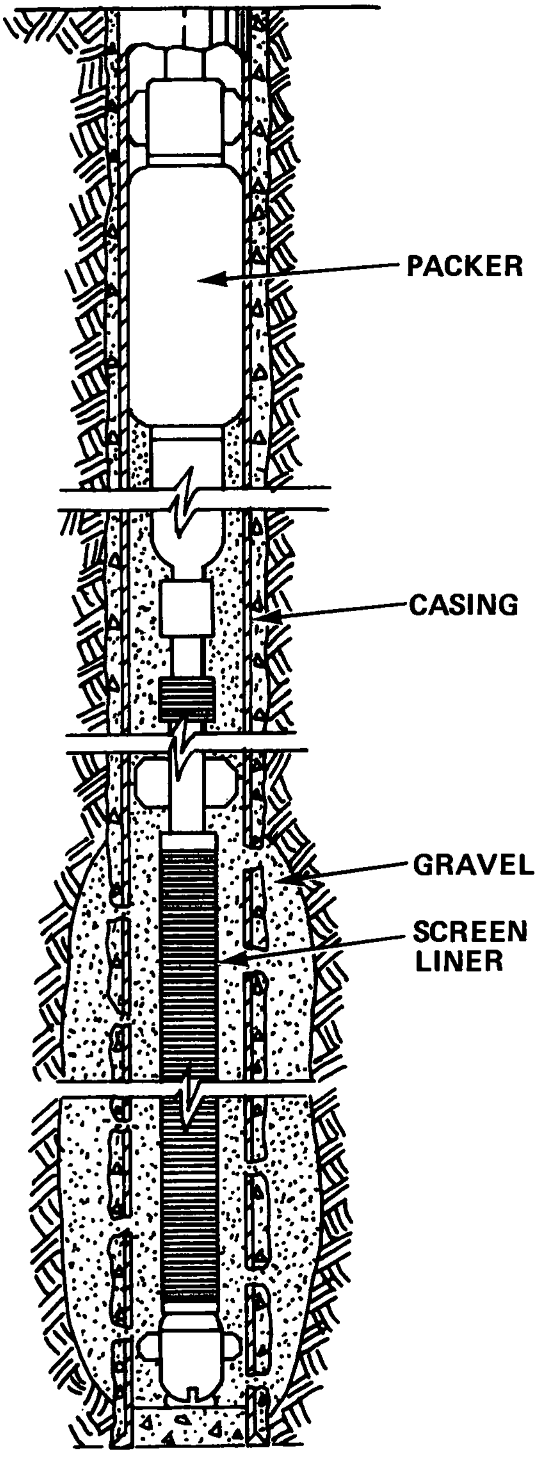
4) Pollution Prevention

Precautions are taken to prevent the pollution of the waters around the well during repair and recompletion operations. All oil and oil-base fluids are collected in tanks or pumped into the flow lines for treatment onshore. Salt water is treated for removal of oil and is disposed of in the ocean.

All of the above-described well repair and recompletion operations are carried out under preplanned procedures designed to keep the well under control. The workover operations are carried out through a blowout-preventer assembly, which assures that the well can be controlled.

e) Improving Recovery

Improved recovery, or secondary recovery as it is sometimes called, is applied to individual petroleum reservoirs to increase the amount of oil recovered above that which might be obtained by natural forces or drives. In some instances, natural drives, such as expanding water contained in the porous rock of the reservoir or gravity drainage of the oil from the rock, together with expansion of oil and gas, result in maximum economic recovery. The natural drives are not universal, and improved-recovery processes are very common. The improved-recovery process is a means of adding energy to the oil reservoir in order to expel oil that might otherwise be unrecoverable. The most common improved-recovery methods are the injection of water or natural gas at high



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 29. Gravel Pack Completion.

pressure. Other media have been used with varying degrees of success, including steam and solvents.

Offshore reservoirs are subject to the same improved-recovery processes as are used onshore. One big difference is that the expenditure for offshore facilities will be substantially higher than onshore. This added investment must provide a reasonable return. Several choices may be available. The most common practice is the installation of improved-recovery equipment on the structure used for drilling of wells. An alternative may be the construction of a separate structure to contain the added equipment. A third system that may be used is the installation of major equipment items onshore with appropriate pipeline connections to the offshore facility.

Each separate petroleum structure and oil-bearing reservoir is different from any other. The normal development of improved recovery involves a data accumulation period which is followed by an engineering evaluation of the need for improved recovery. This evaluation considers available natural drive mechanisms. If it is apparent that additional energy is needed for efficient recovery, then various options are available. The efficiency of various driving media, along with costs to apply, is considered. In some cases, availability of the driving media such as gas or solvents must be considered, and the final choice depends upon an economic comparison of the various options.

The normal time for installing improved-recovery facilities is usually several years after the drilling activity. This allows time needed for engineering evaluation, design, and procurement of necessary equipment.

1) Improved-Recovery Equipment

Improved-recovery equipment, regardless of the recovery method used, can be listed under four categories:

- Fluid source
- Fluid treatment
- Pressure, or energy, increase
- Controls.

For a typical offshore waterflood, the water source may be the surrounding body of water or it may be a water-bearing formation. If the water is taken from the sea itself, equipment may be used which does not contaminate the sea water with lubricating oil or other contaminants.

Water treatment requires removal of objectionable solids, chemicals and bacteria. The method of removal needs to be controlled to ensure that nothing toxic or harmful is included with the returned solids. Solids removal is required to protect high-pressure pumps and piping, or else erosion of these devices will be hazardous to man or other equipment, or cause downhole equipment failure. Such failure could result in injection into the wrong formation.

Chemicals are used to prevent corrosion and to prevent the buildup of bacteria or plant growth. Corrosion has the same effect as erosion in presenting hazards. Bacteria or plant growth in a system can contaminate water or eventually create hazardous operating conditions.

All waterfloods require increased pressure at some time. This is done with pumps, either simple plunger type or rotating centrifugal type, which impart energy to increase the water pressure sufficiently to inject into the formation. These pumps are sized for optimum conditions of throughput and pressure and are driven by some power device, such as an internal-combustion engine (running on natural gas or diesel fuel), an electric motor or a fuel-fired turbine. The pump drivers create normal, usually not significant, engine pollution problems.

It is important that all piping and equipment be designed for the highest expected pressure with reasonable safety factors. It is required that the equipment have controls installed which will provide optimum safety to personnel, to adjacent property and equipment, and to the equipment itself. For example, if pressure should reach a level of questionable safety, the system should automatically shut down to maintain safe control.

The use of gas injection offshore is more difficult than water injection, because compression equipment is heavier and more bulky than water pumps. High-pressure gas requires greater precautions than high-pressure water. As a rule, gas as an injection fluid is more expensive than water. On the other hand, if gas produced along with oil is not marketable, its use for injection may be a conservation measure, since this re-injected gas may be beneficially used later.

Gas may be cleaned and dehydrated by a number of different systems, all of which involve bulky pressure vessels. Heat is generally required, but direct-fired vessels are avoided offshore insofar as possible, and nonflammable heat-transfer fluids are commonly used. High-pressure gas is often used for artificial lift and cleaning, and dehydration equipment as well as compression equipment may be present whether gas is injected or not.

Gas compressors are similar in principle to water pumps, although relatively more costly for initial investment and operation. Control of gas injection by electronic or pneumatic devices is well established and no difficulties along this line are anticipated.

2) Pollution Sources

The base fluid injected for improved recovery is seldom a source of pollution. The most common source of water for offshore waterflood operations is the sea. Such water is usually chemically treated to prevent the growth of bacteria and algae. Some of these chemicals are designed to inhibit growth and obviously would be detrimental if released in large quantities before injection into the reservoir. Treating chemicals, upon injection, tend to be absorbed by the reservoir rocks as the water permeates through the rock and, although part of it may be produced back to the surface, in general, only the oil content of produced water constitutes a pollution hazard.

Natural gas is frequently re-injected into the formation for improvement of recovery efficiency. The gas under high pressure requires safety measures to protect the entire structure, but seldom has the capacity to pollute.

Other injection media occasionally used for improved recovery can be handled safely along with other fluids in the normal production equipment. Steamflood, where live high-pressure steam is injected, is occasionally used onshore, although infrequently, if ever, offshore. Special non-polluting additives to thicken or increase viscosity of the injected water may improve the drive efficiency. Solvents in the form of ethane, propane and butane are sometimes injected and are recovered from the produced oil.

B. Air Pollution

1. Drilling

In the drilling operation, whether onshore or offshore, the well is either an exploratory well or a development well. The frequency with which wells are drilled will depend on geological interpretations and economics. The length of time required to complete or abandon the well will depend mostly on the geology of the area, and can take from a few days to a few years. Those phases or events during drilling and producing operations which may lead to the release of contaminants to the atmosphere are described below.

The need for control of air contaminant emissions during drilling operations for oil and gas is limited partly because of the areas in which these operations are conducted and the inaccessibility of control and recovery facilities, but primarily because the operations do not normally cause air pollution. Of course, unusual situations such as blowouts are impossible to predict, and the control and preventive devices are usually sufficient. Most drilling rig prime movers are natural gas-fueled internal-combustion engines or diesel engines. The exhaust from either does not contribute to photochemical smog. Properly adjusted diesel engines do not emit smoke in violation of air pollution control regulations.

a) Blowouts

Normally, drilling muds and blowout-prevention devices do control the natural pressure in a well. But occasionally a blowout at the wellhead will occur and some contaminants from the oil and gas will be released until control can be established. Most blowouts, however, are gas-well blowouts. Oil blowouts are rare during drilling operations but do occur at times. Hydrocarbon liquids and gas plus hydrogen sulfide vapors and salt water are the major contaminants which may escape on these rare occasions.

b) Well Testing

The initial gas or oil produced from a well cannot be directed into regular production facilities until the necessary tests are completed. The testing time required, of course, varies with each well, but the average for an oil well is 2 or 3 hours. For a gas well, the average testing time ranges from 2 to 4 hours for a development well and from 1 to 7 days for an exploratory well, depending on the area and the type of formation being tested. Also, the amount of gas or oil initially produced and the rate of flow vary greatly for different wells. Because of the short testing time required for development wells, the initial production of gas or oil is relatively small, but gas from an exploratory well can flow at a rate from a few thousand cubic feet per day to millions of cubic feet per day.

Oil or gas produced during the well-testing programs is passed through the required equipment, such as separators, tanks and vent lines, but must be disposed of ultimately. Well-testing gas is usually burned, emitting carbon dioxide and water vapor, and only small amounts of other contaminants, into the atmosphere. The oil produced during well testing is usually not a substantial quantity and may be discharged into waste pits and burned, releasing products of the combustion of hydrocarbons and some products of incomplete combustion. This practice is becoming less prevalent and has been outlawed in several states.

c) Stimulation

Conventional well-stimulation methods do not contribute to air pollution, but the use of nuclear devices for stimulation of gas wells could possibly allow radioactive substances to escape if an error has been made in the preparation of the shot hole. To date only two nuclear devices have been fired, and preliminary results from both of these experiments indicate apparent success.

2. Production and Marketing

The methods used in the production of marketable oil and gas are designed to retain and recover all other products which can be sold or used commercially or industrially. Normal production is directed toward the marketing of gas or oil, and the treatment methods are generally used to remove undesirable substances and to improve the quality of these main products.

Most of the air contaminants associated with the production of oil or gas are emitted as a result of the venting or burning of vapors and liquid waste materials. The air contaminants most often emitted are: unburned hydrocarbons; products of combustion; products of incomplete combustion; and acid gases, such as hydrogen sulfide and sulfur dioxide. However, the concentration of air contaminants from oil or gas production varies greatly with location and concentration of producing facilities. In isolated areas, or where the production facilities are widely scattered, control of air contaminants is often not necessary or feasible. Control and special treatment facilities, such as natural gasoline plants, are usually located in the more developed or highly productive areas.

The production of oil and the production and sometimes further processing of natural gas have a relatively low potential for contribution to the air pollution problem. Proved techniques for the control of air contaminants have been used throughout the production and marketing operations, some of which are listed below:

- Gas-gathering systems to a process plant
- Pressure-relieving or blowdown system to a flare
- Vapor-recovery system for useful products
- Fuel system use of nonrecoverable products
- Proper storage vessels for volatile liquids and gases
- Sulfur-recovery plants.

However, the development and production of new control devices is a feasible means to further reduce or eliminate the emission of air contaminants. The development of a smokeless or non-luminous flare for individual well testings would be useful to control the emission of products of the combustion of hydrocarbons. Also useful would be a means to reduce or eliminate the acid-gas emissions from gas treatment plants when the volume of hydrogen sulfide is too small or the carbon dioxide-to-hydrogen sulfide ratio is too great to economically justify a sulfur-recovery unit. Several states have adopted new regulations which will require that all sulfur-recovery plant emissions be oxidized so that no hydrogen sulfide is emitted.

a) Oil

In a producing oil well, the fluid is either naturally flowing, artificially lifted by induced pressure, or pumped. The oil from a pumping well usually has very small amounts of gas, if any, associated with it, and the oil may be treated only for water removal before being moved into the stock tank. The oil from a flowing or artifically lifted well has varying amounts of gas associated with it, and it must go to a separation unit. Normally, additional treatment is also necessary to make the oil merchantable.

The techniques of oil and gas separation have improved through the years, and vertical, horizontal and spherical separators, each with its particular advantages, have been developed. The pressures at which separations must be made range from just above atmospheric pressure to above 1,000 pounds per square inch, depending upon the pressures produced at the wellheads and those required by the gas-gathering systems.

If a use or market for the gases from the separators is available, such as pipeline sale, industrial use or cycling operations, then the gases are gathered and moved to a plant to make the gas merchantable. These special treatment plants are usually located in the more developed or highly productive areas, and some oil fields in such areas have "no-flare" regulations which require that some use be made of the gases from the separators. However, oil production facilities located in isolated or underdeveloped areas sometimes cannot economically gather the gas and make it merchantable. In such cases the gases from the separators must be disposed of.

Another step in the production of oil is that of emulsion breaking, which separates or "breaks" the fine particles of immiscible liquids which are dispersed or "emulsified" with the oil. The procedure is done in a heater-treater. The residue liquids, usually salt water, collect in the bottom of the heater-treater (sometimes called flow-treater) and are discharged to a disposal facility.

Following this treatment, the oil is usually moved into stock tanks. Normally the oil at this time contains dissolved light gases, which tend to evaporate and thereby enrich the air space in a vented tank with hydrocarbons. When the enriched air is displaced, some hydrocarbon escapes to the atmosphere. For this reason, large crude storage tanks are often equipped with floating roofs to avoid a vapor space, or hydrocarbons are recovered from displaced air when it is economically feasible to do so.

b) Natural Gas

In the production of natural gas, the gas is usually passed through a separator on the lease to remove any free liquids. In some cases, when large pressure differentials can be utilized for expansion refrigeration, moderate recovery of natural gas liquids (NGL) is effected on the lease in a low-temperature extraction unit. The natural gas from the lease facilities is usually gathered to a central point for gas dehydrating, gas treating and, where economics warrant, recovery of natural gas liquids.

Most pipeline transmission companies require the gas to contain no more than 7 pounds of water vapor per 1 million cubic feet, and often less than 7 pounds is desired. This requires that the gas be dehydrated. The most common dehydration methods are absorption in glycol and adsorption on solid dessicants.

Natural gas treating is primarily concerned with the removal of two impurities: hydrogen sulfide and carbon dioxide. A number of methods have been developed or improved during recent years for this purpose. The method used is generally determined by the concentration of the impurities in the gas. Treated gas will usually contain no more than 0.25 grains of hydrogen sulfide per 100 cubic feet, and no more than 1.0 percent of carbon dioxide. When the hydrogen sulfide content of the inlet gas is high enough to provide economic justification, a sulfur-recovery unit is installed downstream of the acid gas-removal plant.

One of the following methods is generally used to recover the natural gas liquids: (1) oil absorption, (2) low-temperature refrigeration, (3) adsorption, or (4) some combination of these methods. Recovered products are usually stored in pressure tanks for transportation to refineries or petrochemical plants as feedstocks.

3. Disposition of Waste Materials

The recovery of certain substances from waste materials is largely a control measure, but the concentration of the substance must be sufficient to justify special processing, and a treatment plant must be located within a reasonable distance. Vapor-recovery systems within a process plant usually use either: (1) recompression and condensation or (2) readsorption in oil.

Waste materials which cannot be recovered are disposed of by means which are designed to minimize the contribution to pollution of the environment. For example, non-condensable hydrocarbons can sometimes be used and consumed in the fuel system of the process plant. Vapors which are unsuitable for use in fuel systems are usually disposed of by flaring, and only as a last resort are they vented into the atmosphere. Acid gas vapors, for instance, must be flared when a sulfur-recovery plant is not installed. Also, relief valves on pressure vessels are frequently piped to the flare to reduce the fire hazard within the plant. The location and height of the vent or flare stack and atmospheric conditions govern the ground-level concentration of the contaminants emitted.

The disposal of liquid waste materials is usually accomplished by dumping into waste pits and burning. Very seldom can the residue liquids be recovered or used in fuel systems, and of course they cannot be vented or flared. In oil production, the dregs from the heater-treaters are normally burned in waste pits. This burning has been allowed by most state air pollution control boards when it is not practical to transport the waste liquids for recovery or to dispose of them in some other manner. Such burning will probably not be allowed under new state regulations required by the Clean Air Amendments of 1970.

C. Land Pollution

Each oil company keeps a watchful eye on field drilling activities, to minimize the possibility of pollution accidents. The Federal Water Quality Administration (now EPA) estimated that of the 10,000 oil spills a year, 7,500 are in port and harbor areas.[222] (Chapter Seven discusses the major oil spills on water.) Gas-well gas containing significant amounts of hydrogen sulfide presents a special air pollution hazard. Operators take extra precautions to protect employees and the public when drilling to formations expected to contain this deadly gas.

Of the 2,500 ground-spill occurrences, most are small and are hardly likely to cause observable ground pollution. The industry is cognizant of the short- and long-term biological and ecological significance of changes, effects and consequences upon the environment, and companies, both individually and through the American Petroleum Institute, are conducting research on the problems of oil-spill cleanup.

1. Blowouts During Drilling

One potential source of land pollution to which operating companies have given a great deal of attention is a blowout during drilling. As a result, in relation to the number of wells drilled, the frequency of blowouts is very small. According to Rush Johnson Association, a Houston insurance firm, 106 blowouts occurred in drilling 273,000 wells in 8 major oil-producing states from 1960 through 1970.[223] Most blowouts are from high-pressure gas rather than oil. With gas, any ground pollution would be from drilling mud blown out of the hole or salt water produced with the gas.

The basic technical causes and means of controlling blowouts have been described in the preceding section of this report describing drilling operations in water-covered areas. Because drilling operations on land are still far more frequent than over water, however, it is appropriate to describe here in more detail the attention which the industry has given to training in well control.

The producing industry and some service companies have developed well-control training programs to give drilling superintendents and drilling engineers the necessary understanding, skill and practice in well control.[224] During a 16-month period in 1967 and 1968, the American Association of Oilwell Drilling Contractors (AAODC) reported that it conducted 100 schools for more than 2,000 trainees. Also, the AAODC has furnished drilling workers with more than 3,000 manuals on how to control formation-fluid kicks, which can be stopped if properly handled but, if uncontrolled, may develop into bad blowouts. Many operating companies conduct similar training schools on kick control for their own employees.

For example, an oil company initiated such a program in April 1968. It consists of classroom seminars on all facets of deep, high-pressure drilling, with special emphasis on containing well kicks. The program employs a practice well to make sure participants are confident before beginning to work at actual well sites. Each student is required to analyze and control a simulated kick on the training well. The training is intensive because each instructor handles only one student.

2. General Measures to Prevent Spillage

As oil field operations are conducted under a wide variety of circumstances (ranging from high-pressure to depleted, high-water cut reservoirs), rules must vary to control the accidental release of pollutants. Similarly, a wide variety of detection, alarm and shutoff systems are employed.

In essentially depleted reservoirs, daily visual examination is usually all that is needed to assure proper and safe operation. When necessary, specific safety and anti-pollution devices are installed. Gas-detector and alarm systems are normally used in enclosed areas such as townlot drilling and production sites, which have deep cellars and are enclosed behind a high wall. Production vessels and water separation devices have high-level, low-level and pressure alarms and shutdown devices. Special alarms and control devices shut down shipping pumps from one or several wells in the event the pumps have been accidentally actuated. Auxiliary power supply equipment and approved firefighting systems and pumps are also used to prevent accidents which may result in pollution.

In producing operations, small spills, ruptures or leaks may occur in field flow lines. As in petroleum pipeline operations, many lines of oil, gas and water that run from the producing wells to the tank battery areas are under regular surveillance. Sections of increased wall thickness or high-yield pipe are normally used when conditions require it. Cleaning and inspection of pressure vessels, electronic and magnetic inspection of high-pressure lines and vessels and measured flow of electrical currents that can damage installations, if not controlled by cathodic protection, are carefully engineered and scheduled. Expansion loops and pipe supports are used when deemed necessary.

Corrosion control is increasingly being stressed in all phases of production, from the "downhole" conditions up through the pipelines and into the receiving tanks. The use of inhibitors for internal control as well as cathodic protection for external control are in common usage and are employed whenever conditions so dictate.

3. Disposal of Wastes

a) Saltwater Brines

During production, large amounts of salt water are usually produced as oil fields age. Such water can create pollution problems from producing wells on land or freshwater-covered areas. Its proper disposal has been and continues to be of major concern to producing operators.

According to a study of the Interstate Oil Compact Commission (IOCC), up to 25 million barrels of salt water are produced daily from the Nation's oil wells.[225]

This study shows further that 72 percent of the water produced is being reinjected into the ground, either for secondary recovery of oil or into nonproductive saltwater-bearing zones that have no commercial value. Prior to returning salt water obtained during production to underground formations, extensive geologic and engineering studies are made to ensure that no damage is done to freshwater horizons. Where proper natural conditions exist, this disposal method is desirable, both from commercial and ecological standpoints. Subsurface disposal, whether for improved recovery or for disposal only, is strictly regulated by state conservation agencies.

The IOCC study also indicates that 12 percent of the salt water extracted during production is put into nonpotable water bodies, approved disposal sites, or is suitable for use in irrigation or for livestock. Another 12 percent is poured into unlined pits where it percolates into the ground. When this is done, studies are conducted to ensure that such seeping water does not migrate into nearby freshwater supplies. However, unlined pits are not allowed in some areas (e.g., Texas). The remaining 4 percent was reported as having been poured into nearby rivers. Government authorities do not permit disposal of salt water into freshwater streams, although it may be disposed of in saline bays and estuaries and offshore.

b) Other Wastes

Sumps that receive borehole cuttings and waste liquids are sometimes lined with impervious membranes to prevent seepage into the ground. Waste liquids are then treated and neutralized, and the disposal pits are refilled with native soil to original grade after usage. More often, metal tanks receive all waste material. The tanks are then hauled off to an acceptable area to dump the contents. Contracts with service companies now commonly include clauses making the contractor responsible for keeping the operation clean.

It also has become fairly common practice to use deep wells for the disposal of a variety of toxic and difficult-to-treat materials, such as radioactive chemicals and some types of oil residues.[226] Because of the risk that any underground formation may fail to hold such materials, there are studies under way by the government and industry to provide guidelines for any future extension of this practice.[227]

4. General Measures to Contain Spills

Offshore equipment and programs for containment and removal of pollution must be extremely elaborate. On land, however, pollution dangers are generally not as great. Thus, programs to prevent the spread of ground contamination range from the simple one of damming a ravine or gully to hold spillage to a fairly complex waste-treatment system in townlot operations.

The rupture of a tank can release a large volume of liquid. It is common practice and a legal requirement in many areas to surround the tank battery with a fire wall, concrete or earth-filled, that is capable of holding the total volume of any liquids that would be contained in all tanks within this area. As the name implies, this wall is so designed to contain a fire in a small area. Of course, it also contains spills. Advanced safety techniques now available in metallurgy, construction and electronics are enhancing overall accident prevention and are, in many areas, permitting the phasing out of fire walls. Automation programs are also drastically reducing the number of field tanks required in production.

5. Maintaining the Environment

In isolated areas, more attention is being concentrated on good housekeeping practices during drilling and production operations. Ground holes are being filled to prevent the accumulation of contaminants. Erosion is being guarded against in Alaska by the planting of new cold-climate grasses. Efforts are being made to collect all trash and debris.

The industry has been careful to control the abandonment of wells. Surface areas also are being cleaned up and returned to original conditions as nearly as possible. Most states have regulations governing downhole abandonment. Also, many local authorities issue rules to control the surface environment. The City of Los Angeles Municipal Code, for example, gives the chief zoning administrator authority to set conditions, ranging from aesthetics to safety, that must be met prior to granting drilling permission in urban areas. In addition to action by regulatory bodies, most modern lease agreements spell out specific proper abandonment procedures.

Chapter Five

REFINING

A petroleum refinery is a complex combination of processes and operations designed to separate crude oil into its fractions which are then further processed to break down, polymerize, reform or otherwise rearrange hydrocarbon molecules to provide the desired component streams which are then treated and blended into finished products.

The refinery is a partial exception to the previously described concept of the petroleum industry as a network of the arterial flow of liquids in a closed system, in that many refining processes involve the deliberate vaporization of most of the petroleum fractions. In other process steps, gases are generated, such as light hydrocarbons and hydrogen sulfide, which create possibilities for atmospheric emissions that are absent in the arterial pipeline systems. Nonetheless, refining processing steps are performed within a closed system consisting of fractionation columns, reactors, absorbers and strippers (in other words, inside pressure vessels as distinct from piping); piping of liquids is also an essential part of the refining system. So, while such handling involves greater opportunity for emissions, the system is still closed during normal operation.

Section 1.
BASIC REFINING OPERATIONS

The number and types of processing units vary greatly for individual refineries. The entire operation, however, can be conveniently discussed in terms of four major steps--separation, conversion, treating and blending.

Crude oil as it is delivered to the refinery is a mixture of thousands of different hydrocarbons (compounds of hydrogen and carbon), together with other constituents in trace quantities such as compounds of sulfur and nitrogen. The crude oil is first separated by distillation into selected fractions; the relative volume of each fraction is determined by the type of crude oil used.

Since the relative volume of each fraction produced by merely separating the crude may not conform to the relative demand for each fraction, some of the surplus separation products are converted to products having a greater demand (e.g., heavy naphtha to gasoline) by splitting, uniting or rearranging the original molecules. For example, the yield of gasoline from the separation of most crude oils is about 25 percent of the volume of crude processed. However, the crude must be made to yield almost 50-percent gasoline to supply the demand for gasoline without producing excess quantities of other crude oil constituents.

The quality of the finished gasoline is usually much higher than the gasoline which occurs naturally in the crude oil. The interweaving of the four major processing steps--separation, conversion, treating and blending--to produce the required product slate from a modern refinery is described in the following paragraphs. (More detailed descriptions and flow diagrams for refinery processes are readily available.)[228]

In addition, since the refining segment of the oil and gas industry is dependent in a major way on the use of water for both cooling and processing purposes, the use of water with respect to petroleum refining will be described.

A. Separation

Separation processes are used throughout a refinery, with the most widely used being fractional distillation. Solvent extraction, absorption and crystallization are also used, but to a much smaller extent.

Separation by fractional distillation depends entirely on the relative volatility characteristics of the various hydrocarbons in a mixture; that is, the temperature at which the several compounds vaporize. Volatility can be expressed as the boiling-point temperature of the various hydrocarbon compounds. For example, gasoline is a liquid that vaporizes at certain temperatures, while kerosine and gas oils require still higher temperatures for vaporization. Volatility is associated with the size of the molecule; in general, the larger the molecule, the lower the volatility.

Hydrocarbon boiling points (and condensing points) range from about 250 degrees Fahrenheit below zero up to more than 1,000 degrees Fahrenheit above zero. Because different hydrocarbon compounds have different boiling points, they also condense at different temperatures. Liquid hydrocarbon mixtures contain a variety of low- and high-boiling components. By elevating the temperature above the initial boiling point, low-boiling hydrocarbons are vaporized from solution. This separation process, which can be carried out in a multi-stage manner, is generally referred to as fractional distillation. In modern refineries and natural gas processing plants, mixtures to be separated by distillation are pumped through rows of heated steel tubes, and the resulting mixture of hot vapors and liquid passes into a closed vertical tower known as a fractionating column.

The top of the column is cooled, and in the distillation of crude oil, those gases which do not condense are carried from the top of the crude fractionating column. Gasoline is condensed at the top. The less volatile products condense farther down the column, the lighter ones to be treated and sold directly as jet and diesel fuels and the heavier to be used as conversion-process feed. The liquid residue, drawn off at the bottom of the column and vacuum flashed to remove heavy gas oils, is used as asphalt or conversion-process feed. All fractions obtained by distillation of crude oil are known as "straight-run" products.

B. Conversion

Conversion processes, which involve a change in size or structure of the hydrocarbon molecules, convert some of the straight-run products into others in greater demand. The more common conversion processes are--

- Cracking processes (thermal, catalytic and hydrocracking)
- Combining processes (alkylation and polymerization)
- Rearranging processes (catalytic reforming and isomerization).

1. Cracking

In the cracking operation, large molecules are decomposed by heat into smaller, lower-boiling molecules. At the same time, some of the molecules combine (polymerize) to form larger molecules. The usual products of cracking are gaseous hydrocarbons, gasoline, gas oil, fuel oil and coke. In the past, cracking was accomplished solely by the application of heat and was known as thermal cracking. The modern cracking practice is to apply heat to the petroleum fraction in the presence of a catalyst. During the catalytic-cracking process, the coke by-product deposits on the catalyst and is burned off in a separate regenerating vessel. The catalyst increases gasoline yield and improves gasoline quality. Charge stocks for catalytic crackers are usually heavy gas oils drawn off near the bottom of the crude fractionating column or distilled under vacuum from the straight-run residue. The asphaltic material remaining after vacuum distillation can be blended to produce commercial asphalt products or residual fuel oil. Alternatively, the asphaltic fraction can be thermally cracked to produce petroleum coke and lighter products or can be gasified to produce hydrogen used in the refinery process.

Hydrocracking, which has been extensively applied in recent years, is a catalytic-cracking process carried out in a hydrogen atmosphere and at very high pressures. The presence of hydrogen allows cracking of the feedstock to extinction, producing only gasoline and jet fuel with essentially no coke formation. Feedstocks are normally extra heavy gas oil from the crude oil distillation unit and heavy gas oils fractionated from catalytic- and thermal-cracking products. The process consumes very large amounts of hydrogen, and the requirements usually cannot be met solely by the refinery processes which produce hydrogen as a by-product. Therefore, a hydrocracking unit normally requires a supporting hydrogen plant which manufactures hydrogen from natural gas, refinery fuel gas or heavy residue and water.

2. Combining

Combining processes may be defined as those in which small molecules of various types are made to combine to form more useful, larger molecules. Thermal or catalytic cracking of high-molecular-weight hydrocarbons forms a class of hydrocarbons called olefins which are deficient in hydrogen. The light olefins have limited utility except in petrochemical manufacture, but through alkylation, they can be converted into high-octane gasoline. Alkylation processes use sulfuric or hydrofluoric acid as a catalyst to combine olefins with isobutane. One well-known constituent of the resultant gasoline is isooctane. Polymerization combines light olefins to form a gasoline blending component. Phosphoric acid is usually used as the catalyst for this reaction.

3. Rearranging

Rearranging processes are those in which the molecule is changed to produce a product of different characteristics. Catalytic reforming uses low-octane gasoline as a feed stock and by molecular arrangements produces a much higher octane number, along with large quantities of hydrogen. In this process, the feedstock is passed over a platinum catalyst at high temperature and in a hydrogen atmosphere. Isomerization, like catalytic reforming, converts low-octane materials to a high-octane gasoline blending stock. Unlike catalytic reforming, no significant amount of hydrogen is produced as a by-product.

C. Treating

Crude oils normally contain small amounts of many impurities, with the major undesirable constituent being sulfur. Sulfur in crude oil is usually found in combination with hydrogen or hydrocarbons as hydrogen sulfide (H_2S), mercaptans (R-SH), sulfides, polysulfides and thiophenes, or ring compounds with sulfur as a member of the ring structure. During the refining process, some of the original sulfur compounds are often converted to hydrogen sulfide and to lower-molecular-weight mercaptans.

Sulfur removal from both products and intermediate feedstocks is becoming more universal in oil refineries for a number of reasons, including improved product quality, sensitivity of certain catalysts to sulfur poisoning, use of crude oils relatively high in sulfur content due to the depletion of low-sulfur crudes, and the obvious need to reduce emissions of sulfur to the atmosphere which occur when sulfur-containing fuels are burned.

1. Hydrotreating

The platinum catalyst used in catalytic reforming is extremely sensitive to sulfur poisoning. Thus the low-octane gasoline streams from crude oil distillation, hydrocracking and coking units must be treated for sulfur removal prior to processing on the catalytic reformer. Also, the distillate fractions from the crude distillation and hydrocracking units usually are treated for sulfur removal before being sold as jet and diesel fuels.

Catalytic hydrogen treating, called hydrotreating, is extensively used in a modern refinery to accomplish the above needs. It involves a mild, selective hydrogenation which converts organic compounds of sulfur, nitrogen and oxygen into hydrocarbons and removable hydrogen sulfide, ammonia and water. The hydrogen sulfide is removed by an extraction process and converted to elemental sulfur or sulfuric acid. Hydrotreating also converts diolefins (gum-forming hydrocarbons) into stable compounds, while minimizing saturation of desirable aromatics. Hydrotreating requires large quantities of relatively pure hydrogen, most economically supplied by catalytic-reforming units; and the two processes--catalytic reforming and hydrotreating--are often found together.

2. Chemical Treating

The use of chemical treating to directly remove sulfur compounds from refinery hydrocarbon streams has declined as hydrotreating has flourished. Chemical treating processes are used, however, to remove from processing streams such impurities as carbon dioxide, oxidants and various corrosive compounds.

D. Blending

The last major refinery operation step involved in the manufacture of most finished products is blending. Motor gasoline leaving the refinery is a blend of various components, including reformate, alkylate, straight-run, thermally and catalytically cracked gasoline, and necessary additives. The vast numbers of lubricating oils are blended or "compounded" from a relatively small number of refined based stocks. Asphalt is often blended from selected residue based stocks as dictated by the particular application desired.

Thus, a modern oil refinery, operating continuously, converts crude oil of little use to the consumer into a variety of marketable petroleum products.

Figure 30 is a flow diagram for a typical modern refinery.

E. Water Use

Refineries are relatively small consumers of water even though they are large water users, but discussion can be misleading if "use" is not defined. Use can mean intake, consumption or circulation. Water "intake" or "withdrawal" or "raw water" is the water taken from a source which may be a public water supply, private well, river, lake or saltwater source. It may be used once, then discharged, or it may be used many times before it is discharged. Water "consumed" is water which becomes a part of a plant's product, is lost by evaporation or is otherwise no longer conveniently available in the immediate area. "Reused" water is that water which is used more than once, either by recirculation in a cooling tower system or by successive use for one or more additional purposes after initial use.

1. Quantities Used

A 1960 survey of petroleum refinery water use extrapolated to estimate total U.S. capacity showed--

	Billion Gallons per Day
Water Intake (Fresh)	1.90
Water Intake (Salt or Brackish)	1.71
TOTAL INTAKE	3.61
Water Reused	12.61
Water Discharged	3.35
Water Consumed	0.26

These values may be compared with 1955 data for all water uses.

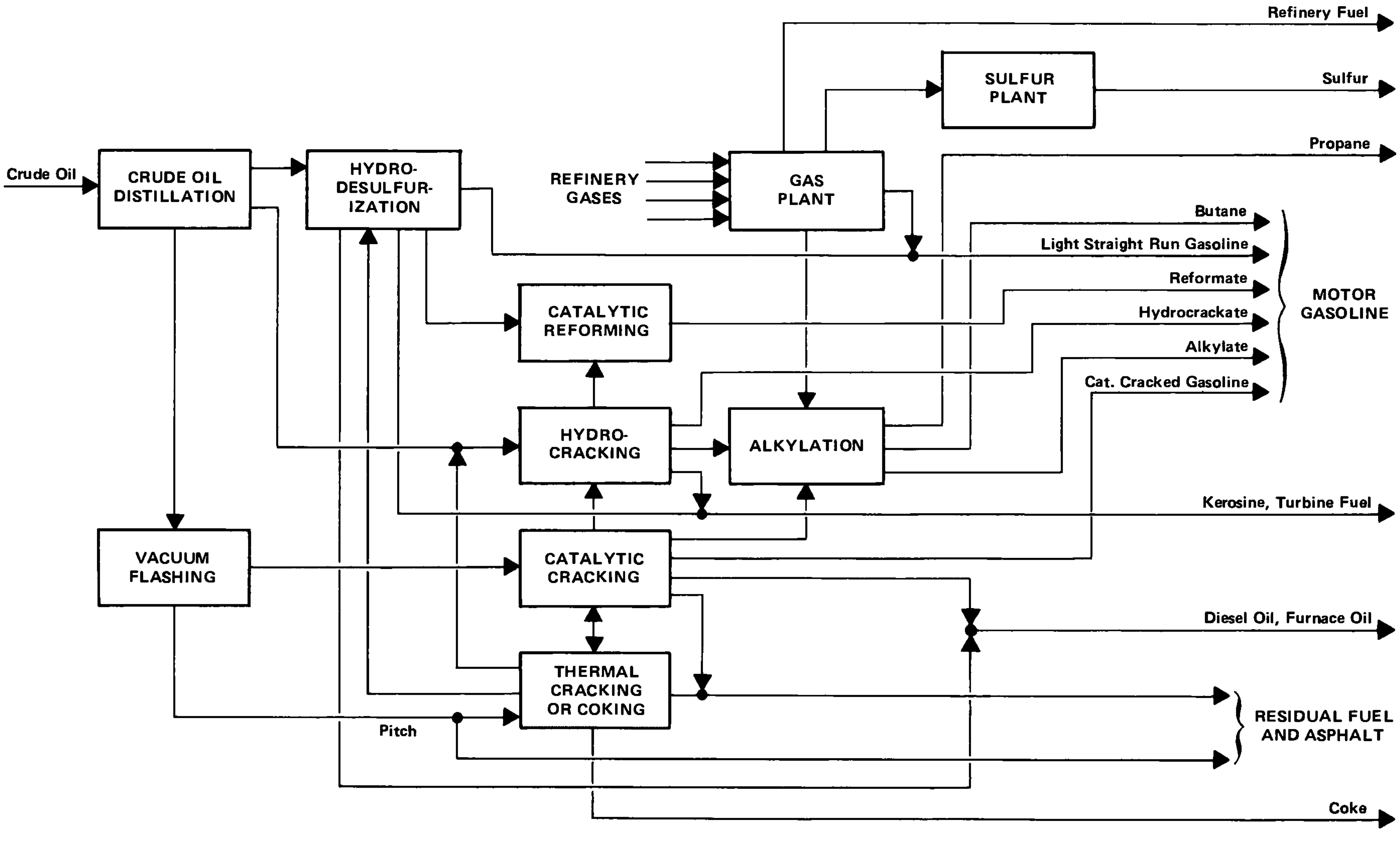


Figure 30. Modern Refinery Simplified Flow Diagram.

	Billion Gallons per Day	
	Intake	Consumed
Irrigation	116.3	91.8
Steam Electric Utilities	76.6	0.2
Industrial & Miscellaneous	49.2	6.9
Public Water Utilities	16.3	3.3
Rural Domestic	5.4	4.2
TOTAL	263.8	106.4

According to the above data, although the refining industry requires large amounts of water, its freshwater intake is less than 0.7 percent of total U.S. withdrawals, and its consumption is only about 0.25 percent of total U.S. consumptive use. These figures in themselves serve only to place refinery *intake* requirements and consumptive use in their approximate relation to national requirements. They do not reflect the real refining use of water which is so important in conserving water supply and which is also closely related to refinery waste-water treatment and control. These aspects will be discussed later in more detail.

2. Types of Refinery Water Uses

Water serves a variety of refining needs, most of which fall under the classifications of cooling, processing, steam generating, potable water use or sanitation.

Cooling and condensing account for most of a refinery's total water needs. A refinery is made up of a number of different process units in which the product(s) from one unit becomes the feed(s) to others. Individual units vary widely in their functions, types of feed and products, but they involve similar equipment such as furnaces, fractionating towers, reactors, heat-exchange equipment, pumps, vessels, valves and piping. In most units the feed must be heated or vaporized to promote the desired reaction or permit the required separation of products, and the products in turn must be condensed to a liquid and cooled to a safe temperature for storage or product blending. A large amount of heat is recovered by the use of heat exchangers to transfer heat between fluids; e.g., heat contained in a hot product which must be condensed or cooled is transferred to a cooler feed stream which must be heated. This conserves fuel and reduces cooling-water requirements. Nearly all cooling water is used in shell- and tube-type condensers or coolers and does not come in direct contact with the stream being cooled. Such waters are generally not subject to chemical contamination, but on some occasions such waters may become contaminated with oil from exchanger-tube leaks or breaks.

Although much smaller quantities of water are required for process purposes, the possibility of contamination is high. Crude oil normally contains salt and other matter which is normally removed by water washing to avoid corrosion or fouling of process equipment. Water is mixed with crude oil in "desalters" specifically designed to provide intimate mixing of water and crude, and to break the resulting emulsion and separate the oil and water phases. Other process waters are used to wash traces of treating chemicals from product streams. Water used in pump glands and for flushing lines and other equipment in preparation for inspection and maintenance work may also be considered process water.

Modern refineries require large quantities of water for generation of steam for power, for use in processes and for heat. Water suitable for steam generation requires extensive treatment. Most of the steam is condensed in closed systems and is normally reused.

Potable water requirements for drinking and sanitary needs are small and appropriate to the number of people involved.

3. Water Quality Requirements

The quality required of the waters for the various uses just described differs, but for a particular use during refining are not substantially different from other industries. Waters used for cooling purposes range from very soft to very hard, from fresh through brackish to sea water, from waters of very low turbidity to highly turbid waters carrying a heavy silt load--in short, from waters of very high to very poor quality.

Experience has shown that water treatment techniques are available to raise raw water, almost regardless of its initial quality, to a quality suitable for industrial cooling use.

Process water quality requirements vary with the specific process use, but the quantities are small and quality requirements are generally not of great consequence. Cooling water, treated or untreated depending on circumstances, or certain waste streams are adequate for most process uses. One notable exception is water required for desalting. Here condensate or soft water is desirable to avoid scaling in heat-exchange equipment. Soft water is also preferred for use in washing out traces of caustic soda from treating operations to eliminate line plugging due to scale formation.

Quality requirements are quite important for water used in steam generation. This is particularly true in the case of boilers or steam generators operating at 600 pounds per square inch guage or higher. Conventional chemical treating, ion-exchange and filtration techniques--singly or in combination--are used to attain the requisite quality.

Potable water requirements are no different from those in any other activity. Although the quality of water for various uses is an important consideration, it is seldom a matter of overriding significance in refinery location or operation.

4. Water Reuse

Water reuse is becoming an increasingly important factor in the design of refining water supply and waste-water control systems. Individual plant practice on reuse varies according to local circumstances. Reuse, particularly for cooling purposes, may be practiced for one or more of the following reasons:

- To conserve water when water supply is limited
- To minimize intake volume when raw water quality is such that extensive pretreatment is required
- To minimize effluent volume and facilitate a high degree of effluent treatment when it is required
- To control thermal pollution.

Minimizing effluent volumes by reuse is particularly helpful in reducing the capital and operating costs of the high levels of waste treatment necessary to improve the quality of some receiving waters.

Late in 1967, the API Committee on Disposal of Refinery Wastes surveyed reuse practice in refineries to--

- Determine refining industry water requirements
- Determine the extent of water reuse and conservation
- Obtain information on ways in which water is reused
- Provide background information for industry personnel in evaluating their own water use practices.[229]

Questionnaire replies were received from 94 refineries representing 61 percent of the 10,451,600 barrels of crude oil processed by the industry. The data were tabulated on two bases of classifications:

- An operations complexity classification
- A daily crude capacity classification.

The two classifications were as follows:

Class	Operation Complexity Classification Description
A	Topping
B	Topping and Cracking
C	Topping, Cracking and Petrochemicals
D	Topping, Cracking and Lubes
E	Topping, Cracking, Lubes and Petrochemicals

Daily Crude Capacity Classification (Barrels per Day)
0- 10,000
11,000- 50,000
51,000-100,000
over 100,000

All volumes of water were expressed as 42-gallon barrels of water per barrel of crude processed (BW/BC).

Table A in Appendix C summarizes the data by refinery operational complexity, showing average values for each classification. Table B summarizes the same type of information on water use according to refinery size. Table C shows the extent of the variation of refinery water use practice within refinery complexity classification.

Although reuse of process condensate is small in proportion to cooling, it is important in terms of pollution control. These waters usually contain ammonia, sulfides and phenolics as pollutants, some of which are removed in the reuse process.

It is interesting to note the increasing use of air cooling, particularly with newer and more complex refineries. At the time of the survey, air cooling on the average supplied 6.7 percent of cooling requirements, a figure quite likely to increase, although air cooling cannot, for technical and environmental reasons, replace all water cooling.

All uses of water, to a greater or lesser degree, are subject to contamination. Water use, water reuse and waste treatment are closely interrelated and the ties become stronger as we call upon water resources of a relatively fixed amount to supply increasing water needs while at the same time we try to improve the quality of these same water resources.

Section 2.
WATER AND LAND POLLUTION CONTROL

The Nation's 281 refineries have waste-treating systems that handle various types of liquid and solid waste.[230] These include oil-contaminated water, water used in cooling, water used in processing, and sanitary and storm waste water. In addition, sludges from storage tanks, chemical treating and other operations must be disposed of.

The largest volume of water used or circulated in refineries is for cooling (heat removal).[231] Refineries maintain records of the sources, characteristics and quantities of waste-water streams.

A. Sources of Refinery Contaminants

For the most part, the sources of contamination of ground and water by refinery operations are the same, the only difference being whether the contaminating substance is discharged or leaked from the refinery system into land or water. Even when wastes are discharged or leaked into the soil, they are generally carried or spread by water. However, though the contaminant may be the same, its effects on a body of water are more variable and far-reaching than on land. Therefore, the coverage of this section will be devoted primarily to water pollution control.

The characteristics or properties of various contaminants from refining operations and their sources can be discussed most conveniently together. It should be pointed out that individual streams may have several properties, but only the more significant of these will be noted. The following headings indicate the predominant contaminants or waste characteristics. They represent those qualities of refinery wastes that are normally of most significance, although others such as hardness, color and salinity could be included. As stated or implied, the list also represents those properties of receiving waters likely to be affected by the addition of refinery effluents. The purpose of refinery effluent treating is to minimize these pollutants.

Petroleum. Oil is the most obvious pollutant from refining operations and its removal from waste waters has long been of primary importance. If present in amounts sufficient to be visible, oil is nearly always considered objectionable on surface waters even if its presence may not interfere with the beneficial water uses to be protected in a particular area.

There are many ways in which oil can enter a refinery waste-water system. It may come directly from accidental spills; leaks from lines, valves or vessels; leaks around pump packing; product sampling; leaks in shell and tube condensers or coolers; and maintenance operations. It may come from those operations in which oil and water are brought in direct contact as from crude desalting operations, product washing following chemical treating, barometric condensers, process unit overhead accumulators, and tank water drawoffs.

Without proper maintenance, oil-contaminated drain water or leakage from vessels tends to soak into the soil if it is not properly routed to a treatment plant. Although vigorous efforts are made to eliminate or minimize these sources of oil leakage, it is assumed that oil can and will get into the refinery waste-water system, and facilities to cope with it must be provided

Oxygen Demand. Substances susceptible to oxidation cause waste waters to exhibit "oxygen demand" either as chemical oxygen demand (COD) or biochemical oxygen demand (BOD). COD is the amount of oxygen expressed in milligrams per liter required to oxidize components of a waste by *chemical* reaction. BOD is the amount of oxygen expressed in milligrams per liter utilized by *microorganisms* in stabilizing the waste in a specified time period. Dissolved oxygen is of great importance and the major objective of municipal and most industrial waste-treatment plants is to reduce the oxygen demand of the plant effluents sufficiently to maintain specified levels of dissolved oxygen in the receiving waters. The oxygen-demand load placed by an effluent upon a given stream must not overtax nature's ability to maintain desired oxygen levels in the stream.

Hydrocarbons, although only slightly soluble in water, contribute to oxygen demand. So do most other organic compounds such as amines, furfural and methyl ethyl ketone used in refining processing in closed systems but sometimes lost in small amounts. Phenolics and sulfur compounds from cracking operations or product treating are also contributors.

Taste and Odor. Taste and odor is a particularly important quality of those waters used for potable supplies. The property is usually evaluated by an odor panel which tests the odor of a series of waste dilutions (with odor-free water) under controlled conditions. The dilution at which the odor is barely perceptible is called the threshold odor number (TON). The procedure may also be used to determine the dilution at which the character of the odor is barely recognizable. This is called the recognition odor number (RON) and is generally a smaller number. Aside from safety from a health standpoint, the most important quality of potable water is palatability, determined by the interrelated qualities of tase and odor judged by the above tests.

Taste and odor in natural waters can be caused by algae or other natural factors and by various compounds in waste waters. Some of the substances in untreated refinery wastes that contribute taste and odor components are hydrocarbons, sulfur compounds, phenolics and nitrogen compounds. Such compounds originate from waters which have been in direct contact with hydrocarbon streams, or come from leaks or discharge of spent chemicals.

Extensive research has been conducted on the taste and odor characteristics of refinery effluents.[232] This research has resulted in contributions to the effectiveness of secondary refinery waste-treatment processes in reducing taste and odor. Research is also being applied to the persistence of odor when treated wastes are subjected to conventional potable-water treatment processes, and the identification of specific compounds responsible for the persistence of refinery-associated odors.

Acidity and Alkalinity. Acidity and alkalinity may have profound effects upon the ecology of receiving waters. This property of refinery waters must be kept within a range that will not cause either excessively low or high pH (see Glossary) in the receiving waters or interfere with refinery waste-treatment processes.

Leaks or losses of acid or caustic solutions used in refinery processes, or improper disposal of the spent solutions, can cause undesirable pH in waste waters.

Toxicity. Toxicity of a substance, or waste, is its presence in sufficient concentration to cause harm to plant or animal life through either external or internal action which produces deleterious environmental or physiological effects. Some sources of toxicity in refinery waste waters are condensates containing sulfides, ammonia and phenolics; spent caustic from product treating which may contain sulfides, mercaptans or phenols; and chemicals such as chromates and biocides used to control corrosion and microbiological growths in circulating water systems.

Turbidity and Suspended Matter. The term "suspended matter" applies to finely divided particles that settle slowly or not at all, as well as to larger and heavier particles that may settle even in flowing streams. Turbidity and suspended matter may be of natural origin or due to waste discharges or other human activity. In natural receiving waters, both aesthetic and recreational values may be damaged by degradation of appearance, soiling of boats, and effects on aquatic life by exclusion of light and buildup of bottom deposits. Excessive suspended matter in a refinery waste system can stabilize oil-water emulsions making oil removal a much more difficult process as well as increasing the amount of oily sludge that must be disposed of.

Some sources of solid material in refining operations are clay and silt from plant construction or soil erosion within plant boundaries, rust and carbon particles from maintenance work, coke and catalyst from process operations, oily sludges from tank cleaning, and sludges from both water- and waste-treatment practices.

Nutrients. Nutrients are included in this discussion because of the dominant role they play in the increasingly important problem of receiving-water enrichment and attendant nuisance growths of algae and weeds. Nitrogen and phosphorus are the elements of most concern. They occur in natural waters, in soils and in precipitation. They may be discharged in large quantities in municipal wastes and in lesser amounts in industrial wastes. Those refineries which include biological treatment in the lineup of waste facilities need nutrients to satisfy the cellular requirement of the microorganisms upon which the process depends. Ammonia present in refinery waste streams usually meets and occasionally exceeds nitrogen requirements, but it is frequently necessary to add some form of phosphorus. Sources of nutrients in refinery waste water include ammonia-bearing condensate waters from certain process units and blowdown from boilers and cooling towers where phosphates are added as a form of treatment.

Temperature. Temperature is another property of water that is receiving increasing attention. It is a controlling factor in chemical and biological reaction rates. Solubility of oxygen, so important to aquatic life, varies inversely with temperature. Aquatic life of various types can live only within certain temperature ranges, and organisms may die if the temperature changes too rapidly.

B. Waste Control Methods

A waste-water system is an essential part of every refinery installation. The systems used do not follow a standard pattern, but rather are developed or designed to fit a particular refinery's operation, topographical features, and whatever water supply and water disposition assets or peculiarities exist. A waste control system is not a static thing and its day-to-day operation should not necessarily be expected to remain constant. Its design cannot be a precisely sized arrangement of equipment; it must be one which is adaptable to loads that vary with production changes and to overloads that result from emergency conditions.

Very broadly speaking, a refinery waste system usually consists of--

- Drainage and collection systems
- Gravity type oil-water separation facilities and auxiliaries required to remove oil and sediment
- Facilities to handle segregated chemical solutions or other process wastes to control the effects of pollutants causing toxicity, taste and odor, etc.
- Some form of secondary treatment following gravity separation where required.

The first two items have been used so universally in refineries as to be considered traditional. The latter two are coming into more general use by many plants.

The choice of an overall plan for a particular refinery depends on an evaluation of many factors, some of which are--

- Characteristics of the receiving waters (e.g., flow rate, quality and use--present and projected)
- Regulations pertaining to stream use and quality
- Quality and quantity of the effluent
- Quality and quantity of raw water available
- Refinery water use requirements
- Land area available for waste control facilities.

Refinery waste-water control is discussed below under the main headings of collection and segregation, loss prevention, oil removal, recovered-oil treatment, ballast-water treatment, disposal of spent chemicals, process-condensate treatment, biological treatment, solid wastes disposal, other treatment processes, effluent flow measurement and monitoring, and diffusion of effluents. Not all apply in every location.

1. Collection and Segregation

Collection of wastes is obviously the starting point in any disposal system. The mechanical features of sewers used in refineries do not differ markedly from those in other industries, except that special attention must be given to safety because volatile hydrocarbons are involved. This includes the use of special water seals at manholes and the proper use of sewer vents.

The collection or drainage system is laid out to prevent drainage of storm and other surface waters subject to oil contamination directly onto adjoining properties or into adjacent surface waters. Lines are laid out so that oil contaminated wastes flow by gravity to the oil-water separators. Pumping of oil-water mixtures tends to form emulsions and is avoided.

Usually it is desirable to provide separate, or segregated, sewers to handle various types of waste waters. To do so may permit certain economies in cost of waste treatment since different types of waste can then be treated in the most appropriate manner. The choice of overall plans for collection and treatment depend on many factors. In the final analysis, the scheme chosen should represent the most attractive combination of capital and operating costs for the entire system of water supply, sewers, cooling towers and waste treatment.

Figure 31 is a simplified flow diagram for segregation, collection and treatment of refinery waste waters. It does not represent an existing facility nor is it intended to represent a universally ideal arrangement. Depending upon local conditions, a much simpler or even more elaborate plan may be required. The oil-free sewer collects waste waters which have not contacted oil and are not subject to any other contamination for which treatment must be provided. Although oil-free waters should be safe to discharge directly to receiving waters, the practice is to provide a small separator or pond to trap oil that may somehow find its way into the oil-free system.

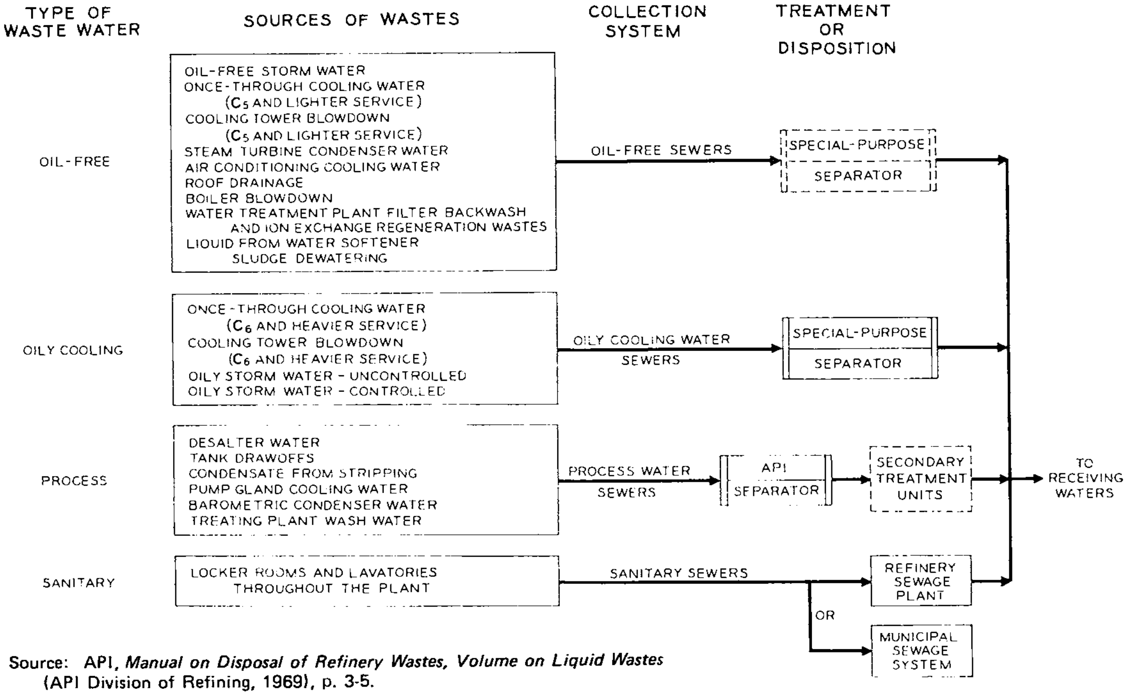
The oily cooling-water sewer system handles waters that are expected to be subject to some oil contamination from leaks in heat-exchange equipment or spills. In the absence of contamination by chemicals or fine solids which tend to stabilize emulsions, separation of essentially all the oil from the water can be readily accomplished.

The process water system collects most waste waters that come in direct contact with oil or are subject to contamination with emulsified oil and chemicals which cause taste and odor, toxicity, or oxygen-demand problems. Water from this system is treated in an oil-water separator, and very often an additional stage or stages of treatment are needed to provide a higher degree of purification.

The sanitary sewer collects sanitary wastes for conveyance to municipal sewers or to refinery treatment facilities. State or local regulations usually determine sanitary disposal requirements.

2. Loss Prevention

Normal small losses of products occur during most processing and handling of hydrocarbons. Normal drippage, sampling and flushing occur during operation and maintenance procedures. This drippage drains into the plant sewer system from paved areas that are regularly cleaned. Emission of air and gases from refinery stacks may contain some fine catalyst dust, but it normally does not pollute land or water surrounding the plant unless a processing unit undergoes a major malfunction.



Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes* (API Division of Refining, 1969), p. 3-5.

Figure 31. Example of a Plan for the Collection and Treatment of Refinery Liquid Wastes.

Some examples of loss-prevention procedures follow.

a) Aboveground Piping

In some refineries piping is installed above ground on sleepers or on overhead racks so as to permit easy detection of line and valve leaks as well as easier and faster repairs.

b) Pumpout Systems

The practice of providing special lines, valves, pumps, etc., needed to pump out the contents of the towers, lines and vessels of process units when they must be shut down prevents large quantities of oil from reaching the sewer and results in operating economies as well.

c) Special Sewers and Sumps

Special facilities are usually provided to collect spills and leaks of solvents or chemical treating agents such as ethanol amines, furfural, etc., for reuse.

d) Elimination of Barometric Condensers

In most cases tubular condensers have been substituted for barometric condensers in which the water and hydrocarbons come in direct contact, to eliminate a major source of oil loss and water contamination.

e) Good Maintenance

The prompt correction of leaks from valve packing, pipe flanges and pump packing greatly reduces oil to the sewers. Losses from pumps are frequently reduced by selection of a different type of pump or by using mechanical shaft seals.

3. Oil Removal

Since oil is the pollutant most closely related to refining, oil removal has been a main objective of refinery waste control. Various methods for oil removal are discussed as follows.

a) Gravity Separation

The basic unit for recovering oil is the gravity-type oil-water separator developed by the American Petroleum Institute and in general use throughout the industry. In many refineries it may be the only major treatment facility required. Operation of the separator depends on the difference in specific gravity of oil and water. Such a unit will not separate soluble substances nor will it break emulsions. Research on gravity separation led to the adoption of fundamental principles which provide a mathematical basis for determining separator shapes and dimensions.

Design equations, nomographs to facilitate design, and a design example are presented in detail in the API *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes, 1969*. This manual also provides construction details of gravity-type separators including trash racks, oil-skimming devices, inlet diffusers, sludge removal and other features. Figure 32 is a typical example of a gravity-type separator. Good practice requires that at least two channels be provided so that operation will not be interrupted when a channel must be taken out of service for maintenance.

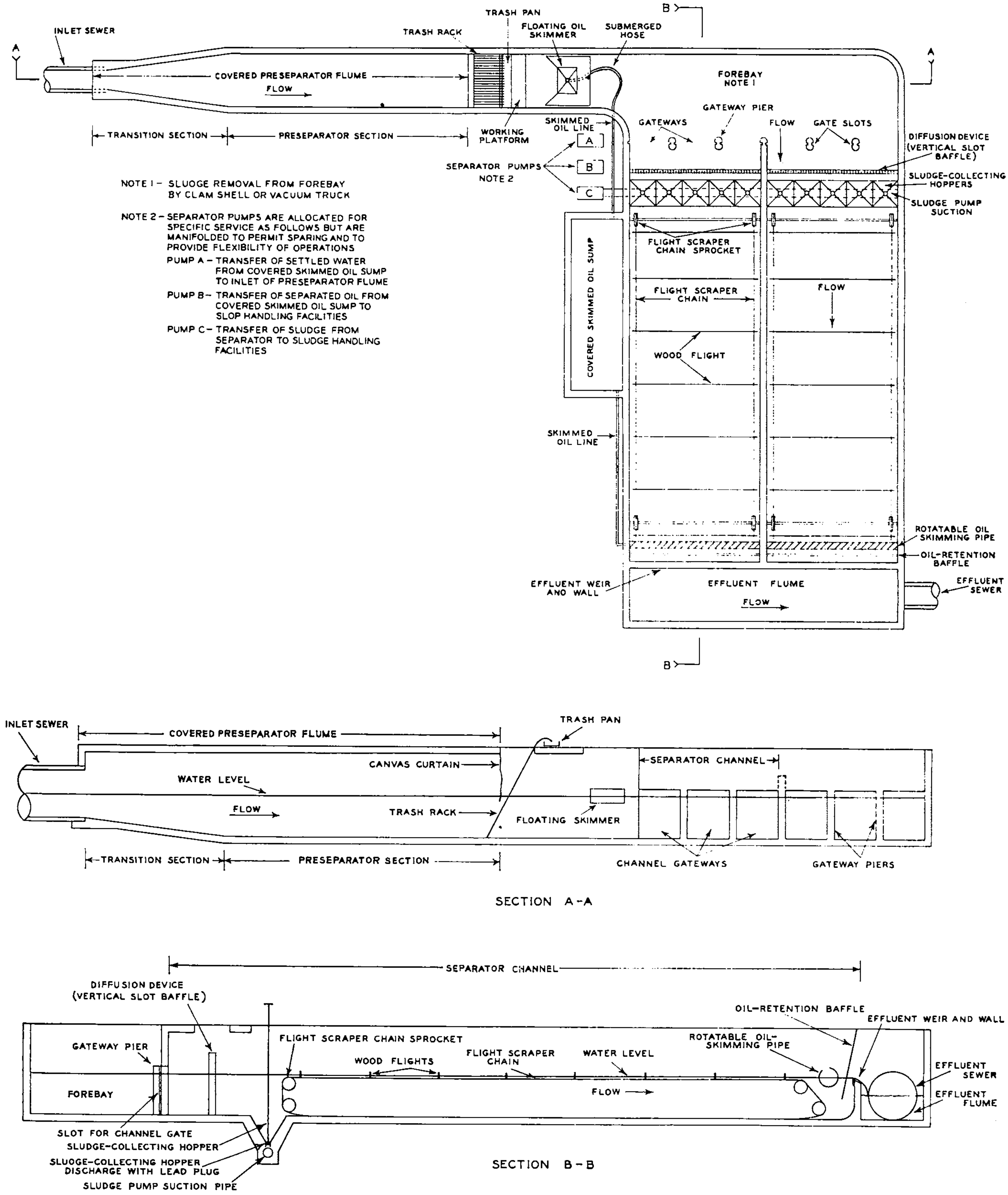
Even the best designed and operated separator will produce poor results if the feed is not susceptible to gravity separation because of dissolved or emulsified oil content or the presence of very heavy oils. If troublesome wastes are handled, they are usually treated individually at their source in order to achieve satisfactory separator performance, or additional (secondary) treatment is provided to produce the required effluent quality.

b) Flocculation and Sedimentation

"Flocculation," as used here, is intended to mean the overall treatment process in which waste waters are clarified by the addition of chemical coagulants (and perhaps coagulant aids) to produce finely divided precipitates which are then agglomerated into larger clumps that can be removed by sedimentation. It is a process which is sometimes used after gravity separation to achieve lower oil and suspended solids contents. The clarity of treated water will depend on the types and quantities of chemicals used, the number of clarification steps, the size of the units and efficiency of overall operation. The equipment used for flocculation and sedimentation of separator effluents is of conventional design, and conventional jar test procedures guide the choice and dosage of chemicals. Operation may be troublesome if feed rates and temperatures vary widely, and sedimentation effectiveness will suffer if too much oil in the feed reduces the settling velocity of the floc particles. Sludge from the unit adds to the refinery's solid-wastes disposal burden.

c) Flotation

Dissolved air flotation is another process for supplemental treatment of oil-water separator effluents to reduce oil and suspended solids to low levels, either to protect receiving waters or to provide suitable feed quality for subsequent biological or other treatment units. Its success depends on the use of very fine bubbles to increase the rate of rise of suspended oil or solid particles so they can be floated to the surface for removal. It is, in effect, just the opposite of sedimentation. Dissolved air flotation can be used alone or in combination with chemical flocculation. Air-flotation units are not as readily upset by fluctuation in feed rate or quality (particularly oil content) as the flocculation units just discussed. The usual method of obtaining small bubbles is to saturate the feed or a recycle stream with air at 2- to 3-atmospheres pressure. Upon release of the pressure across a control valve, air is



NOTE 1 - SLUDGE REMOVAL FROM FOREBAY BY CLAM SHELL OR VACUUM TRUCK

NOTE 2 - SEPARATOR PUMPS ARE ALLOCATED FOR SPECIFIC SERVICE AS FOLLOWS BUT ARE MANIFOLDED TO PERMIT SPARING AND TO PROVIDE FLEXIBILITY OF OPERATIONS

PUMP A - TRANSFER OF SETTLED WATER FROM COVERED SKIMMED OIL SUMP TO INLET OF PRESEPARATOR FLUME

PUMP B - TRANSFER OF SEPARATED OIL FROM COVERED SKIMMED OIL SUMP TO SLOP HANDLING FACILITIES

PUMP C - TRANSFER OF SLUDGE FROM SEPARATOR TO SLUDGE HANDLING FACILITIES

Source: **API,** ***Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,*** **p. 6-4.**

Figure 32. API Oil-Water Separator.

released from solution in the form of vast numbers of tiny bubbles which form on or are attracted to suspended particles, helping to float them to the surface where they are removed as a froth or scum.

Operating results depend upon the nature (free, dissolved or emulsified) of the oil present in the feed and the type and quantity of chemical additions, if any, that are used. The equipment is available from a number of manufacturers in both package units and larger units constructed on site. Systems are designed to dissolve air in the total feed, in part of the feed or in a recycle stream--each method offering certain advantages. In comparison with flocculation units, air flotation requires lower detention times, offers some possibility of providing an effluent of satisfactory quality without chemicals, and produces a smaller scum volume; however, the method imposes the cost of pressurizing the waste and usually produces a less polished effluent.

d) Filtration

Effluent quality from a gravity separator or other treatment step may be improved with respect to oil and suspended matter by filtration, using hay packed in wire baskets as filters, slow or rapid sand filters similar to those used in conventional water treatment, mixed or multimedia high-rate filters, and even vacuum precoat filters. In addition, to a degree, oxygen demand can be reduced by filtration. The use of filtration is uncommon in refinery-effluent treatment and would normally only be considered for very small volume effluents. High-rate filters, where filtration occurs in deep beds, have been used for large-volume effluents in other industries for oil removal, but have only recently been applied to refinery wastes. Proper selection of filtration method does offer a means of producing a very well polished effluent.

4. Recovered-Oil Treatment

The amount of oil skimmed from API separators is variable, but may be as much as 1 percent of the volume of crude oil processed. Unfortunately, the skimmed oil is not clean oil, but contains solids and water in emulsion form. Some of the skimming may readily separate into an oil layer of relatively low water content, which is suitable for reprocessing, and into a water layer of relatively low oil content, which can be drained back to the separators. However, there is generally an intermediate layer of emulsion that resists separation and must undergo further treatment before an emulsion break is achieved. The general methods of treatment used in refineries are set out below.

Physical Methods. The process of heating emulsions to obtain a break is the simplest and most economical approach available; the use of heat is nearly always helpful. Heat markedly reduces viscosity of the oil phase and helps coalescence and separation of oil and water phases to take place. Distillation is effective for breaking emulsions. Centrifuging in high-speed machines can be effective in making phase separations. Vacuum precoat filtration, although quite expensive, is sometimes very effective in breaking emulsions stabilized by finely divided particles.

Electrical Methods. Some emulsions can be broken under the influence of a strong electrical field. This is the method used in the dehydration of products and desalting of crude oil. When electrical desalting is used for crude oil feeds, some emulsions may be blended along with the regular crude-oil charge. A combination of electrical and chemical methods is frequently successful where neither method above is effective.

Chemical Methods. Emulsions can be broken by chemicals which will balance or reverse the interfacial surface tension on each side of the interfacial film, neutralize stabilizing electrical charges, or precipitate emulsifying agents. A large number of useful proprietary chemical agents are on the market. Anionic and cationic surface-active agents and metal salts normally used in municipal waste treatment, such as calcium iron and aluminum salts, may also be effective. Systematic trial-and-error testing of chemicals is helpful in selecting the most effective and/or economical chemical agent to use.

Actual refinery practice takes many forms. The simplest system consists of holding-tanks operated on a batch basis, usually with the addition of heat and the use of recirculation. Both cold and hot settling are used--with cold settling time varying from 1 day to 4 weeks, and hot settling time varying from 1 to 3 days at temperatures of 150 to 200 degrees Fahrenheit. At the end of each stage of treatment, substantially oil-free water is returned to the refinery separators and low-water-content oil decanted and returned to the refinery for reprocessing. Emulsions remaining after these separations are usually given additional treatment by one of the methods described above.

Various refiners have adopted a wide variety of emulsion-treating schemes--probably no two are exactly alike. Many systems involve a combination of treating methods. Most involve heat and settling time; many involve chemical additions as well; and others additionally involve centrifugation, filtration or electrical methods. The dewatered oil may be charged to crude oil units with or without desalters; to thermal or catalytic units; to coking units, to visbreakers; or to separate distillation units. Water content of recovered oils fed to crude units or separate distillation units may run as high as 2 percent, but water content of recovered oil sent to other types of units is generally limited to 0.3 to 0.5 percent.

5. Ballast-Water Treatment

Many refineries located on navigable waters have installed facilities for disposing of ballast water from tankers and barges. Various state and federal laws prohibit discharge of oil-bearing water from vessels into harbors, coastal waters and inland waterways of the United States. Ballast water may be fresh water, salt water, or a mixture of the two. Fresh water such as that from the Mississippi may contain large amounts of silt. In addition, ballast water may contain finely divided rust and precipitated chemicals from tank cleaning. The oil it contains will range from gasoline to heavy cracked fuel oils. Ballast water discharged from gasoline or light-distillate oil tanks will contain little oil until nearly all the water has been pumped out. On the other hand, ballast water from tanks that had contained heavy fuel oil may have oil dispersed throughout its volume. This is also true of the emulsion from tank cleaning.

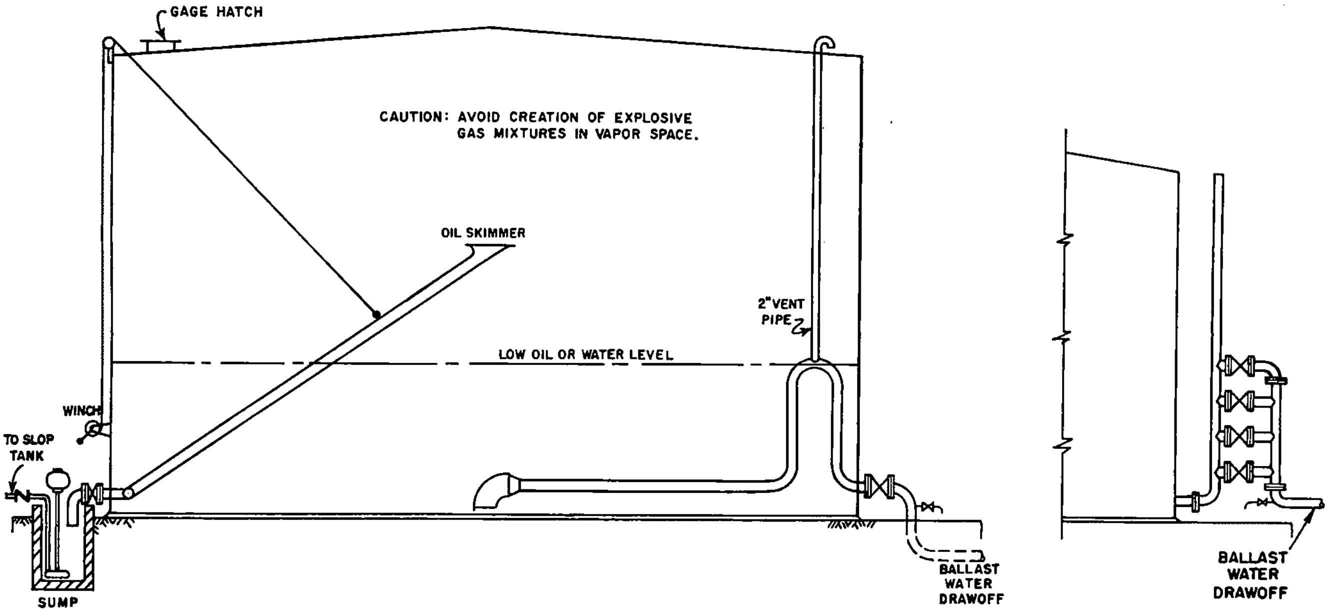
The complexity of the facilities required varies according to the volume and character of the waste waters which must be handled, receiving water characteristics, and pollution control regulations in effect. Direct disposal of ship ballast via the refinery waste-water system is not recommended unless the system has adequate excess capacity to handle the high rates of discharge usually necessary to avoid loss of ship time. Separate systems are usually needed.

The minimum treatment applied to ballast water involves simple settling in ballast-water tanks equipped with an oil-skimming device. A heating coil and an air coil to provide gentle agitation may also be desirable. If simple chemical treatment is effective, provision for injecting treating agents may be included. Figure 33 shows how oil and water are removed from one type of ballast-tank installation. A swing line is used to remove separated oil. Water is discharged from the bottom by gravity, but a syphon breaker is provided to maintain a minimum water level in the tank to prevent accidental discharge of separated oil with the water. One or more tanks installed as in Figure 34 would frequently be used.

Such a simple installation is not always adequate and more complex and efficient facilities may be required to meet local objectives. Figure 35 illustrates a more sophisticated system.

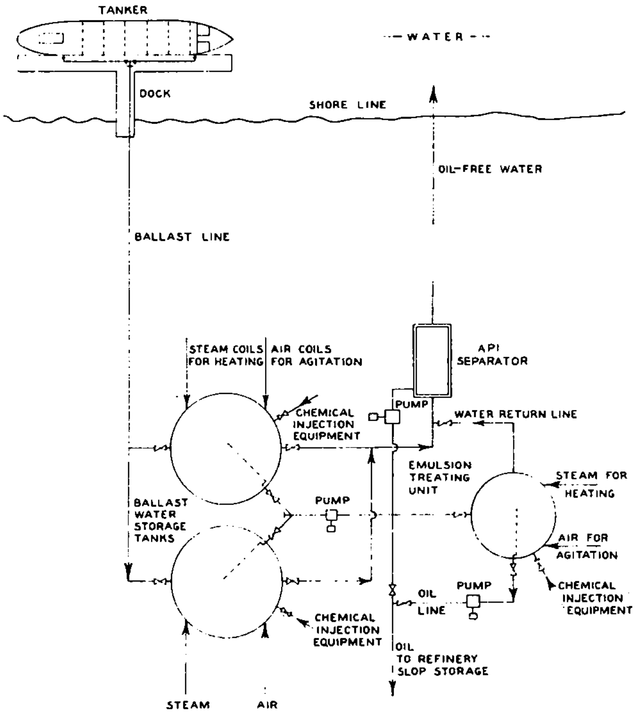
6. Disposal of Spent Chemicals

Numerous chemicals are used in refining, such as caustic soda (perhaps the most widely used), sulfuric and phosphoric acids, amine solutions, furfural and methyl ethyl ketone solvents, cleaning solutions, and water-treating chemicals. Some of these are used in closed systems and do not present a disposal problem.



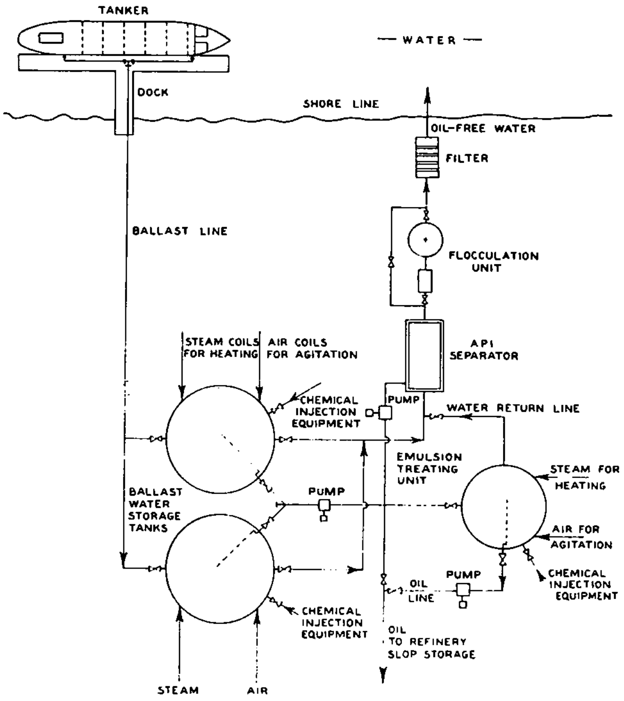
Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* p. 7-4.

Figure 33. Automatic Flow Breakers for Ballast Water Tanks.



Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* p. 7-5.

Figure 34. Example A of Ballast Water Disposal Facilities.



Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* p. 7-5.

Figure 35. Example B of Ballast Water Disposal Facilities.

Others are used in small quantities and become contaminants of the refinery waste water but do not necessarily pose individual disposal problems.

During the disposal of chemicals and solid or semisolid wastes (slurries and sludges) contaminated with oil, leaching into the ground occasionally occurs. These wastes include liquid chemicals such as caustics or acids, clays used to filter lubricating oils, or chemical floc used to absorb oil.[233] Spent caustics used for a variety of treating purposes, spent sulfuric acid from alkylation, and other chemicals used in various quantities and ways usually require special disposal means, as described in the following paragraphs.

Disposal by Sale. Sale is frequently the most attractive method of disposal. It usually requires segregation of special streams and may require changes in operating procedures and equipment and concentration of waste materials (see Chapter Eight). Spent caustics rich in phenolics are frequently sold to manufacturers of cresylic products; sulfide-rich caustic is used in pulp and paper making by some paper mills. Spent sulfuric acid from alkylation and sludge from acid treating is usually returned to the acid manufacturer for reprocessing.

Disposal at Sea. Some refineries have disposed of spent caustics, acid sludges and chlorinated hydrocarbons far at sea, when such disposal has been considered to cause minimal ecological damage. Close cooperation with state and federal authorities must be exercised. In some areas special contracting firms are licensed to haul waste materials to sea, but this is going out of practice.

Disposal by Chemical Methods. Regeneration, air oxidation and neutralization are methods used to minimize the production, handling or disposal of spent caustic solutions. Caustics used to extract mercaptans from hydrocarbon streams can be regenerated by: (1) steam stripping the mercaptans from the solution, followed by incineration or recovery of the mercaptans, or (2) oxidation of the mercaptans to disulfides which can be separated as an oily phase. Air oxidation can be used as a pretreatment for spent caustics containing sulfides or sulfites to reduce their high oxygen demand before they are biologically treated along with other more dilute streams. Spent caustics containing sulfides, phenolics or naphthenates can be pretreated by acid or flue-gas neutralization.

Incineration. Incineration is not a common method of disposing of spent chemicals, although it is used to dispose of materials released from neutralization of spent caustics. Refinery waste chemicals are usually either too low in fuel value or too high in constituents that would cause visible or irritating stack emissions to make incineration an attractive option. At least one company is disposing of oily sludges and spent caustics in a fluid-bed incinerator.

Disposal in Wells. Deep-well disposal can provide a method for concentrated, toxic or odorous wastes (e.g., spent caustics or foul condensates). The method involves the underground storage of wastes in the pores of a geological formation which already contains unusable water. It has been widely used for disposal of oil-field brines, but is not used extensively for refinery wastes. Careful attention to suitability of geological factors and monitoring of practices is essential, as is close compliance with state, local and federal requirements.

7. Process-Condensate Treatment

Various refinery processing operations produce waste water containing dissolved contaminants. For the most part the dissolved contaminants are sulfides, ammonia, mercaptans, phenolics and possibly small amounts of water-soluble organic acids, nitrogen bases and other substances. Their principal sources are condensates from accumulators, reflux drums and knockout pots in catalytic crackers and reformers, cokers, hydrocrackers and crude distillation units. These waters may have high oxygen demand, strong odor, and may be toxic to aquatic life. It is common practice to collect and treat such waters before they are discharged to the waste-water system. Stripping or oxidation is the usual treatment method.

Strippers are of many different types, but most involve the use of either packed or trayed stripping towers in which the feed passes downward and countercurrent to the stripping media which removes hydrogen sulfide, ammonia and, in some cases, phenol. The stripping media may be fuel gas or steam, but steam is most commonly used.

Hydrogen sulfide is easier to remove than ammonia. Since one is an acid gas and the other alkaline, pH plays an important role in their relative removals. Feed pH is sometimes lowered with mineral acid to provide greater hydrogen sulfide removal or to reduce stripping steam requirements. Low pH tends to fix the ammonia as a salt of the mineral acid and reduces or prevents ammonia removal. Without pH adjustment, steam stripping can readily remove 95 to 100 percent of the hydrogen sulfide, and if temperature and stripping steam rates are high enough, ammonia removals ranging upward from 85 percent are possible.

Flue-gas stripping is generally somewhat less effective. Overhead gases are burned in flares or combustion chambers of furnaces. Author Milton R. Beychok has described the types of strippers and their performance and has provided data, methods and examples for stripper design.[234]

Stripped process-condensate water is discharged to the refinery waste system directly, or is reused either for cooling tower makeup or for crude-oil desalting. Substantial reductions in phenolics may result from these reuses.

An alternate means for eliminating sulfides is a sulfide oxidizer. Both process-condensate waters and spent caustics can be oxidized to thiosulfates and sulfates by using air as the oxidizing agent. Mercaptans are eliminated, but other contaminants are not. Off-gases may be incinerated. Figures 36 and 37 illustrate typical stripping and oxidizer installations, respectively.

Several installations of a patented process have been made which recover high-purity ammonia and hydrogen sulfide from foul water--especially from hydrocracking.[235] Economics of the process are highly dependent on the amount and quality of the water available.

8. Biological Treatment

Treatment by biological oxidation is a well-established procedure for removal of organic components in waste waters. The benefits to be gained from biological treatment of refinery wastes are varied and include reductions in oxygen demand, oil content and toxicity, and improvement in taste and odor as well as appearance.

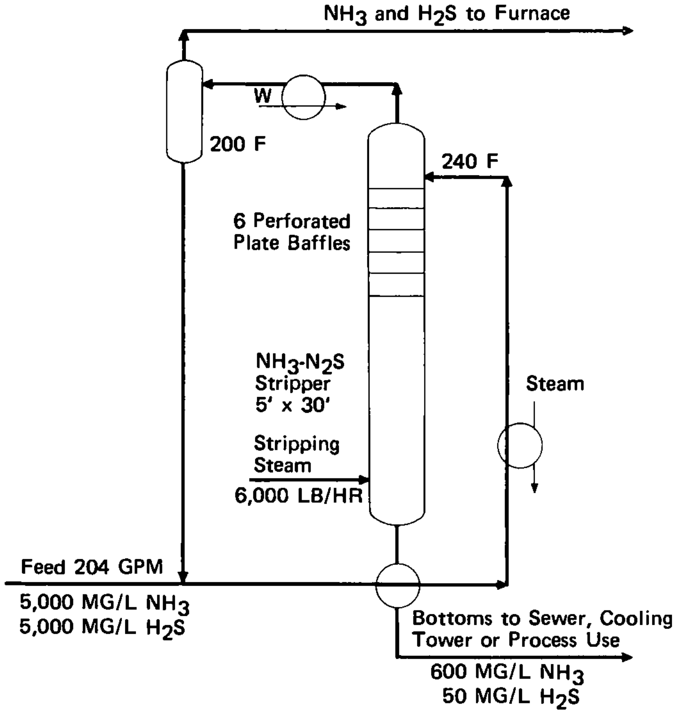
a) Theory of Biological Treatment

Biological treatment depends on the use of bacteria and other organisms to metabolize waste. The same principles of biochemistry and microbiology apply to the treatment of refinery wastes that apply to the treatment of municipal or other organic wastes, and the subject is well covered in readily available literature.

b) Refinery Waste Characteristics

It was noted earlier that refinery waste waters may be segregated according to type, i.e., oil-free, oily cooling, process and sanitary waste. In practice, plans and facilities range from those in which a single sewer system receives all wastes and the combined flow goes through one or more waste-treatment steps in series, to those in which various types of wastes are separately collected and individually treated. Because of the numerous variations that exist, it is improbable that any two refineries have biological treatment feeds with quite the same characteristics. Some of the properties of typical refinery waste may interfere with biological treatment and must be kept within tolerable limits. Oil can be handled to a degree, but research and experience have shown that oil contents higher than about 50 milligrams per liter (mg/ℓ) may cause trouble, particularly in activated sludge-type units. The presence of too much oil will

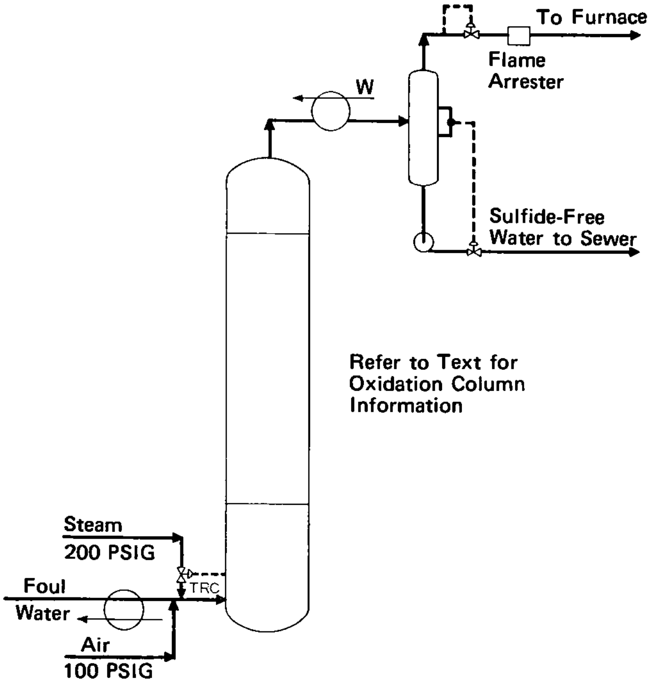
Process: Continuous Steam Stripping of Foul Water Containing NH_3 and H_2S.



Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* p. 15-10.

Figure 36. Foul-Water Disposal--Stripping.

Process: Continuous Air Oxidation of Foul Water and Spent Caustic with Conversion of Sulfides to Thiosulfates at Elevated Temperatures and Pressures.



Source: API, *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes,* p. 15-15.

Figure 37. Foul-Water Disposal--Oxidation.

prevent proper sludge settling, and the process may fail because of loss of active sludge. Temperature of refinery wastes is subject to more fluctuation than municipal wastes and should be held within reasonable limits. Sulfides may reach concentrations toxic to the microbial mass, but even if that does not happen, sulfides place an oxygen demand on the system and may reach concentrations toxic to the microbial mass. Phenolics are readily destroyed in biological systems and very high concentrations in the feed have been successfully handled, but variations should be limited to prevent upsetting the biomass. Attention must be paid to nutrient levels. Although nitrogen is usually present in ample quantity, it may be necessary to add phosphorus in some form.

c) Treatment-Method Selection

Selection of a particular type of biological treatment for a particular refinery can involve many factors. The economics of construction and operation are primary factors (see Chapter Eight), but effluent quality often dictates process selection. Bench-scale studies can be made by several techniques to determine treatability and plant design parameters. It is sometimes desirable to confirm data, particularly with respect to oxygen transfer equipment performance, in pilot plants.

d) Activated Sludge

The activated-sludge process is an aerobic biological-treatment process in which organic impurities are removed by microorganisms suspended within an aeration tank into which oxygen is introduced by one of a variety of means. The microorganisms are maintained in the aeration tank by recycling activated sludge formed in this process. Organic matter is removed by oxidation and synthesis which produces new cellular material. No special sources of bacteria are needed to get the process started. They can be built up from those bacteria which enter the system from ground runoff or are present in the waste. Activated sludge from a municipal plant can speed the process.

The basic process consists of an aeration tank followed by a sedimentation tank in which activated sludge is removed and recycled to the aeration tank. As activated sludge builds up, it is necessary to "waste" some, i.e., remove it from the system and dispose of it. There are many variations of the activated-sludge process, all of which depend on the same fundamental microbiological and biochemical processes. Three types which have been used by the petroleum industry are--

- Complete Mixing, Sludge Return. This has had extensive use in refineries, frequently using a design in which the functions of aeration, sedimentation and sludge recycling are all provided within a single unit. The completely mixed aeration chamber tends to level out variations in waste feed and makes for a more stable system than the conventional activated sludge.
- Complete Mixing, Complete Sludge Wasting. This is the simplest type of activated-sludge system and consists of an aeration tank only. Microbial solids are discharged with the effluent from the aeration tank without subsequent settling and recycling to the aeration tank. Where suspended solids in the effluent are a problem, a retention pond may be provided to settle out solids. Complete solids wasting prevents buildup of activated-sludge concentration in the aeration tank to levels comparable to those in systems with sludge return. To compensate, longer aeration retention times are necessary.
- Conventional Activated Sludge. This involves an aeration chamber, a separate clarifier, and the means to recycle sludge.

Operating data from a representative complete mixing, sludge-return-activated sludge plant treating a total refinery waste with an aeration time of about 3 hours is as follows:

	Feed	Effluent	% Removal
Temperature (°F)	95	95	
BOD (mg/ℓ)	200	26	87%
COD (mg/ℓ)	250	100	60%
Phenolics (mg/ℓ)	12	0.5	96%
Oil (mg/ℓ)	50	2	96%

The effectiveness of activated-sludge processes has been well reported. The same types of equipment are used in refinery and municipal systems.

e) Trickling Filters

A trickling filter is a bed of broken stone, coarse aggregate, or plactic packing with some method of distributing waste uniformly over the surface. A gelatinous film of slime composed of aerobic organisms develops on the surface of the aggregate. As waste water trickles over the film, both dissolved and suspended matter are removed by adsorption and then metabolized by the organisms. Air flows through the bed by convection and provides the oxygen needed to maintain aerobic conditions. The oxidized waste is clarified in a sedimentation tank before discharge.

Trickling filters may be of the standard-rate type which operate on a once-through basis, or high-rate type which may operate on a once-through fashion or with recycle. They have proved ability to withstand relatively heavy shock loads. They also have the advantage of producing less excess sludge for disposal than the activated-sludge process. They are generally not capable of as high a degree of treatment as an activated-sludge unit, but they have the ability to handle heavy loads in terms of pounds-per-day of oxygen demand.

Refinery trickling filters have been used as the sole biological-treatment step but frequently do not provide the high quality of treatment possible with activated sludge. They have also been used as "roughing" devices to even out the organic load prior to treatment by activated-sludge processes. Maintenance and operating costs are low. Initial cost is high, and unless plastic fill is used, land requirements are large.

f) Oxidation and Stabilization Ponds

This is a popular type of biological-treatment system where land is plentiful. The oxidation pond depends on bacteria to aerobically stabilize organic wastes. In heavily loaded ponds, some of the stabilization will occur anaerobically at the bottom. The oxygen for the bacteria is supplied by surface transfer and from the metabolism of algae that grow in the pond. Algae produce oxygen in synthesizing algae protoplasm, and the bacteria utilize the oxygen in synthesizing bacterial protoplasm. The net effect is production of organic matter in the oxidation pond. The pond can produce a more stable effluent than influent, because the degradation of cellular protoplasm is slower than the degradation of organic matter for synthesis of cellular protoplasm, plus the fact that many of the microorganisms settle out and do not depart in the effluent. Loading is limited to oxygen transfer and is affected by temperature, ice cover, turbidity and emulsions which retard light penetration.

Oxidation ponds have been used both as the sole method of biological treatment and as a means of polishing the effluent from other biological-treatment processes. Single and various multiple pond arrangements have been used. Retention times have ranged from as little as 1 day to 90 days. There is so much variation in pond design and operation that "typical" performance cannot be given.

Operating data for a special system with a total retention time of 60 days and covering 19 acres are--

	Influent		Effluent
	Annual Ave.	Range	
Temperature (°F)	--	71-106	--
BOD (mg/ℓ)	54	17-204	Range: 2.5-15
COD (mg/ℓ)	212	147-528	Max. reduction: Summer: 60% Winter: 40%
Phenolics (mg/ℓ)	9.5	3- 23	Ave. reduction: 90% Summer: 98% max. Winter: 96% max.
Sulfides (mg/ℓ)	1	0- 6.5	Nil
Phosphate (mg/ℓ)	6.5	3- 13	1
Toxicity TLm48hour to fat-head minnows, % concentration	41	29- 64	Not toxic at 100% concentration after 48-hour exposure

In locations where land area is limited, stabilization rates can be markedly increased by the use of aeration devices to increase oxygen availability. Extensive use is therefore being made of mechanically-aerated ponds. (Oxidation ponds are less effective under ice cover. Cold weather retards biological action in oxidation ponds.)

g) Oxidation Towers

An interesting innovation in biological waste treatment by at least one refinery involves the use of cooling towers as oxidation towers. In this case careful studies showed that cooling towers could be used both as biological waste-treatment units and to provide the cooling and water reuse required by expanded water needs. The process has been compared with both the activated-sludge and trickling-filter processes and has certain similarities to each. Some biological growth is retained on the fill. However, most of the organisms are suspended in the circulating water. In this system, phenolics were reduced from 360 to 0.8 pounds per day, and BOD from 4,740 to 934 pounds per day. Others have occasionally used cooling towers to reduce the phenolics contained in stripped process-condensate waters. Odors may be a problem when this is done.

9. Solid Wastes Disposal

This is a subject of considerable scope, but only those aspects of solid wastes disposal that are related to refinery waste treatment will be discussed here.

a) Sources of Solid Wastes

All crude oils contain some basic sediment and water which is generally composed of a mixture of water, rust, iron sulfides, clay, sand, etc., produced with the crude or picked up in transit. It either enters the waste system via the desalter or settles out in tanks, which must be periodically cleaned. Surface runoff waters carry slit, which is particularly undesirable if the refinery does not have a segregated sewer system as is usually the case in older refineries. Additional solids may enter the system in the raw-water supply, from water softening or other water-treating operations, from boiler blowdown, from maintenance activities, and from periodic tank-cleaning operations. Many of these wastes end up in the form of oily sludge withdrawn from the bottom of API separators. Additional oily solids result from secondary or auxiliary processes such as flocculation and sedimentation, air flotation, and recovered-oil treatment processes. Waste organic sludges from the various types of biological-treatment processes can be a major problem.

b) Effect on Refinery Operation

Solids entering the refinery waste system add to the problem of sludge disposal from waste-water treating units, but perhaps more importantly, they tend to reduce treatment efficiency by stabilizing emulsions and by becoming coated with oil to the point that they do not settle because of reduced specific gravity. Solids mixed with recovered oil make the processes for emulsion treatment more difficult, and the cycle repeats if unbroken emulsion is drained from the emulsion treater back to the separator.

c) Treatment Methods

A variety of treatment methods are in use. For example, refineries are now employing more efficient methods (including vacuum filtration, centrifuging and fluid-bed incinerators[236]) for separating and disposing of oil sludge from water systems, thus reducing ground pollution within refinery fences to a minimum,[237] as well as reducing water pollution. These methods can best be described in more detail under headings describing the several types of solid wastes.

1) Sludges Containing Water and Solids

The main source of this type of waste is the sludge from raw-water treatment. Best practice is to handle it at its source to avoid contact with oil in the drainage system. If space is available such sludges may be settled in ponds, but under some climatic conditions the bed may never really dry out. Centrifugation and vacuum filtration are much more effective dewatering methods, giving cakes that can be used for fill. There are some possibilities for reuse of water-treatment solids for neutralization purposes or as weighting agents in waste-water flocculation.

A unique situation exists at units making petroleum coke. The usual practice is to remove the coke product by hydraulic jets from the large drums in which it is formed. The water so used may be clarified for reuse in a closed system, and the coke fines from the clarifier are usually pumped over the coke cars which serve to filter out the fines.

Sanitary landfill, if properly located, designed and operated, can be used for disposal of the solid wastes from refinery operations.

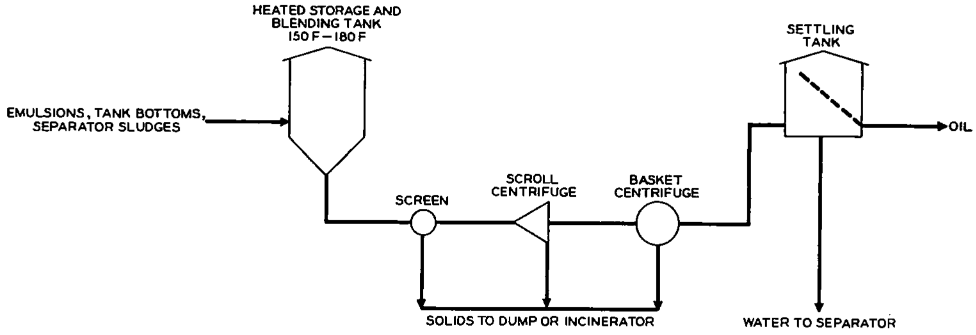
2) Sludges Containing Oil, Water and Solids

These are the sludges that present the most difficult disposal problems. The major source is from the bottom of API separators, but tank-bottom sludges, biological-treatment processes, wastes from chemical flocculation and sedimentation, or air-flotation units are additional sources.

New methods are being developed to handle collected oily sludge.[238] The use of centrifuges for refinery oily wastes is relatively recent. Generally speaking, scroll centrifuges are effective for separator and water-treating sludges; they also can handle relatively high solids loads. They will usually not break emulsions, so either a basket- or disc-type centrifuge is required to handle oily emulsions. Figures 38 and 39 show two different refinery centrifuge installations.

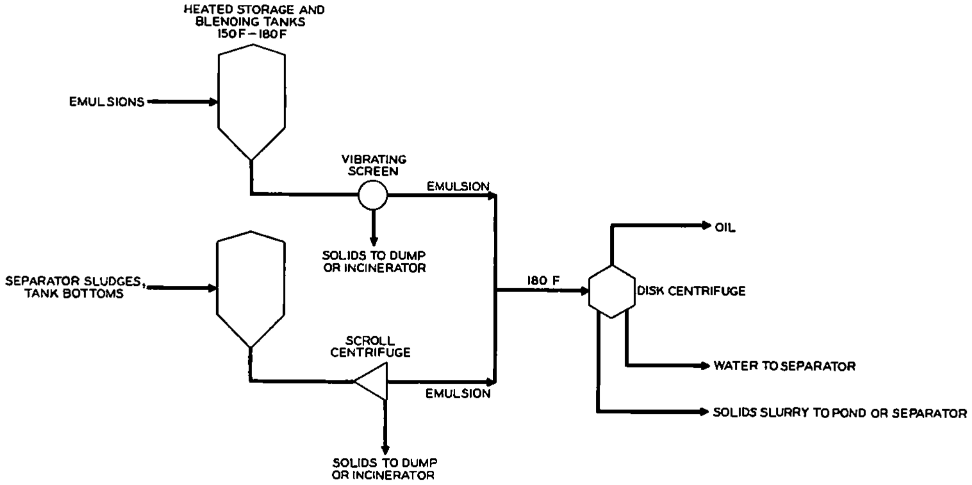
Oily sludges and emulsions can be effectively handled by pressure or vacuum filtration. A precoat operation is usually required and the continuous rotary vacuum filter is usually the type used. Precoat filtration is very effective and gives a cake of sufficient dryness to be permitted to be used for landfill or fed to an incinerator. Both capital and operating costs are high.

Figure 40 shows a typical arrangement. The charge may be separator sludges, oily emulsions, air-flotation froth and tank bottom waste.



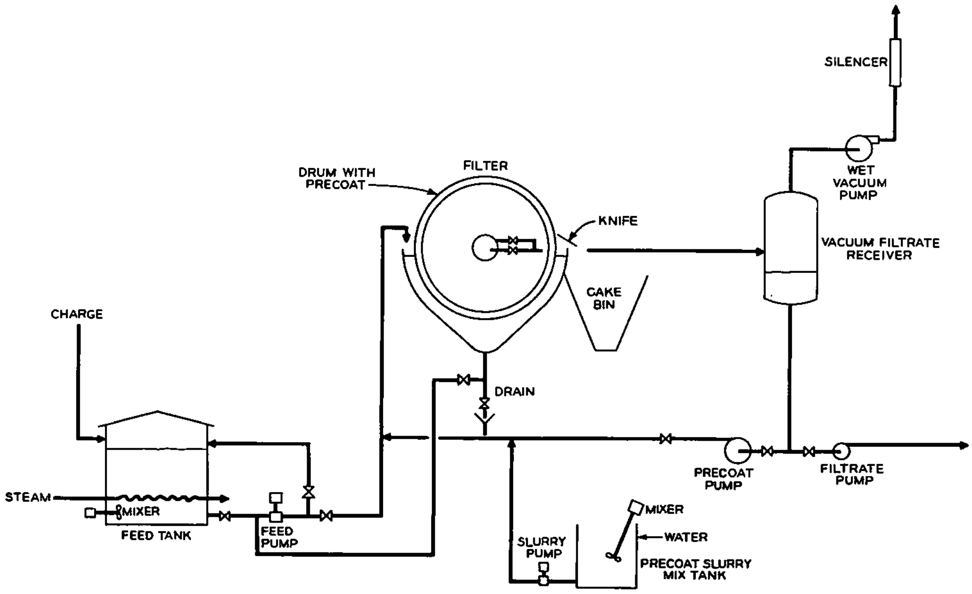
Source: API, *Manual on Disposal of Refinery Wastes, Vol. VI, Solid Wastes* (API Division of Refining, 1963), p. 22.

Figure 38. Arrangement with Scroll and Basket Centrifuges.



Source: API, *Manual on Disposal of Refinery Wastes, Vol. VI, Solid Wastes*, p. 22.

Figure 39. Arrangement with Scroll and Disk Centrifuges.



Source: API, *Manual on Disposal of Refinery Wastes, Vol. VI, Solid Wastes*, p. 26.

Figure 40. Typical Arrangement of Precoat Vacuum Facilities for Handling Sludge.

Fluid-bed, rotary kiln and multiple-hearth incinerators can be used for oil sludges, but pretreatment to concentrate the waste by filtration or centrifugation may be desirable.

At one refinery, a fluid-bed incinerator, which is a closed vessel that heats semisolid wastes to 1,400 degrees Fahrenheit, is reducing wastes without accompanying odors. The highly reduced inorganic ash is relatively inert and can be used for landfill. In another refinery, emulsions are mixed with the feed to a fluid catalytic-cracking unit.[239]

Ponding has long been an economical method of sludge disposal. However, sludge ponds take up valuable space, may be odor sources, and eventually must be cleaned.

It is becoming increasingly difficult to find satisfactory places to haul settled sludge from ponds, but there have been a variety of solutions to this problem. Some wastes are blended with natural soil to provide a mixture suitable for dikes, tank foundations and landfill. At some locations, oily sludge is spread about 6 inches deep in disposal areas, dried, and then blended with earth by bulldozers. Disposal areas are rotated yearly to promote biodecomposition. Such dispersed dumping tends to provide complete disposal and does not progressively degrade the soil. Actually, some advantages in soil stabilization or conditioning may be obtained, depending on the kinds of wastes involved.[240]

Another practice being employed is to spread sludges thinly over a several-acre site within a refinery. Such sludge beds normally biologically decompose within one year, with soil bacteria consuming the hydrocarbons. Several petroleum refiners are exploring the acceleration of such decomposition with bacterial seeding.[241] Exploratory crop studies in laboratories show that this technique can substantially improve formerly contaminated soils.[242]

One manufacturer has recommended that residues of tetraethyl lead (TEL), a toxic waste that accumulates in the bottom of tanks, be spread on land so that oxidation will destroy the TEL. When this is done, the areas are posted and fenced. At one refinery facility, the sludge accumulation from lime-soda treatment of boiler feedwater is combined with sludge from lime-ferric sulfate flocculation of oil waste-water and is trucked to a nearby cement plant employing a wet process.[243]

Concentrated sludges are also often handled by outside contractors, who place them in landfill sites designated by local zoning laws.

3) Biological Solids

Excess biological solids are produced to some degree by most biological processes. If waste loads are low and the aeration time is extended so that endogenous metabolism predominates, excess sludge will be at a minimum and may in fact be balanced by carry-over of suspended solids in the effluent. Conversely, with high waste loading and short aeration, excess solids disposal can be a major problem.

Anaerobic digestion of waste sludge as practiced in municipal plants may be used but can only be justified for relatively large plants. Aerobic digestion of activated sludge can produce a stable material that can be spread on the ground without causing nuisance. Aerobic digestion for as little as 5 days can result in a 70-percent destruction of the active microbial mass and a 55-percent reduction in solids by weight. The process can be accomplished either in an aeration tank or aerated pond, followed by dewatering by conventional means. Sludges can be concentrated in thickeners, centrifuges or air-flotation units.

10. Other Treatment Processes

Although little can be reported at this time, the refining industry is considering possible application of a variety of so-called "advanced waste treatment" techniques that can be applied either to special waste streams or to the refinery effluent. Considerable research has been conducted on the use of activated carbon as a tertiary method of treatment to reduce oxygen demand and threshold odor numbers of refinery wastes to values below those attainable with methods now in use. Ion-exchange, reverse osmosis, filtration and microstaining are other examples of treatment methods which may be utilized as the degree of treatment needed to maintain proper receiving-stream quality increases and as refiners explore ways to increase their reuse of effluent waters.

11. Effluent Flow Measurement and Monitoring

Provisions for measuring and monitoring the plant effluent not only represent good judgment, but are frequently required by regulatory agencies. Analysis and flow measurement are both necessary to calculate waste loads.

a) Flow Measurement

Effluent flow measurements are made by a variety of devices, with weirs and Parshall flumes being the most common. Flow-recording instruments are not usually required, but can be very helpful in conducting waste studies and providing a permanent record of operation. A wide variety of techniques are available to the refinery for measuring or estimating flow rates within the plant for flow in pipes under pressure, flow from pipes discharging to atmosphere, open-channel flow, and flow in sewers.

b) Monitoring

Monitoring is used to--

- Assess the pollution potential of the plant effluent
- Determine waste-treatment performance
- Determine the effects of wastes on receiving waters
- Comply with control agency requirements.

Monitoring may take various forms but most commonly consists of sampling the refinery effluent followed by appropriate chemical and physical tests. There are also biological techniques that offer special monitoring advantages. Frequent visual observation provides a direct warning of upset or emergency conditions so that appropriate action can be initiated without delay. Although monitoring ordinarily is applied to the plant effluent, monitoring of receiving waters may also be conducted since the goal of pollution control is to protect receiving waters for whatever their local purposes may be.

1) Refinery-Effluent Monitoring

Chemical and physical monitoring involves analysis of representative effluent samples, which may either be spot samples, or composite samples taken by hand or automatic sampling devices. Among the tests most often performed are those for oil content, pH, oxygen demand, suspended solids, dissolved oxygen, temperature, threshold odor number, chlorides, phenolics, sulfides and ammonia. Other tests may be required in specific circumstances.

Because protection of aquatic life in waters is a major goal of effluent treatment, considerable research work is being carried out with the objective of developing suitable biological monitoring procedures.

2) Receiving-Water Monitoring

Stream monitoring may take several forms. A growing number of refineries, particularly those building completely new plants, retain a team of experts to make complete biological surveys of the receiving waters before and after the plants are built. Chemical analyses are also included. Benthic organisms, as well as fish, plankton and other organisms collected, are indicators of the biological health of the area under study.

The "diatometer" is a device, developed by the Academy of Natural Science of Philadelphia, which is sometimes used as a continuous biological monitoring device. It is a small floating device, anchored in the stream, designed to collect specimens of microscopic algae, called diatoms, on microscope slides. Diatoms are sensitive to changing stream conditions, and changes in their populations (number of species as well as number of individuals per specie) are indicators of changes in biological health.

Fish boxes placed in receiving waters above and below an outfall and periodic studies of bottom organisms are other forms of receiving-water monitoring.

12. Diffusion of Effluents

A growing number of refineries are finding it advantageous or necessary to use some type of diffusion mechanism for mixing and distributing or dissipating effluents in receiving waters. As receiving waters become more intensely used and reused, the localized areas of lower water quality near waste outfalls become more critical. The use of such mechanisms--the last phase of the waste-control system--can often reduce or eliminate undesirable localized areas of effluent concentration by speeding up the dilution process which would otherwise occur over a long time and distance of stream flow. In determining the type of device needed, the hydraulic, chemical and physical characteristics of both the effluent and receiving waters must be considered. Methods used are not peculiar to the refining industry.

C. Waste Loads

The most comprehensive survey of refinery-effluent characteristics ever conducted was carried out by the American Petroleum Institute in 1967. The main objective was to assess the industry waste loads and current waste-control practices.[244]

1. Refinery Classifications

As discussed earlier, refineries vary a great deal in both size and complexity. The industry has recognized that the degree of refining complexity has a significant impact on the character and quantity of contaminants entering a waste-water system. As downstream processing facilities are added to a simple distillation unit, the initial crude oil charge is successively handled and exposed to molecular changes under the influence of temperature and pressure, often in the presence of catalysts, and may be subjected to a broad range of chemical treatment. Accordingly, a refinery processing classification for purposes of the survey was adopted including the following categories and representing the crude capacities indicated.

The area of petrochemical manufacture has been specifically excluded from discussion in this report to this point. However, categories C and E do reflect petrochemical operations (in addition to aromatics manufacture) carried out by many refineries in conjuction with normal refining processes. Nevertheless, data for all five categories will be included here for the sake of ease and completeness in reporting.

Refinery Classifications

Category and Description	% of U.S. Crude Capacity Included
A. Crude Topping (Atmospheric and/or Vacuum Distillation)	3.0
B. Topping and Catalytic Cracking	27.9
C. Topping, Cracking and Petrochemicals	19.2
D. Integrated (Topping and Cracking plus Lube Oil Processing)	20.5
E. Integrated plus Petrochemical	16.0
TOTAL	86.6

2. Waste-Treatment Classification

The refinery classifications were further evaluated and classified by type of waste treatment. The following conventional *terminal* treatment categories were established:

Category	Description	% of U.S. Crude Capacity Reported
Primary Treatment	Gravity Separation Only	33.0
Intermediate Treatment	Chemical Flocculation Air Flotation--No Chemicals Air Flotation--With Chemicals Filtration	11.2
Biological Treatment	Activated Sludge Trickling Filter Stabilization Ponds --With Aerators --Without Aerators Oxidation in Cooling Towers	42.4
	TOTAL	86.6

3. Results

Table 23 summarizes all waste-load data reported for biochemical oxygen demand (BOD), chemical oxygen demand (COD), oil content, phenols and suspended solids. These parameters are regarded as most significant in current efforts to achieve water quality objectives for receiving streams. The range of all data reported for each parameter in each category is presented together with the arithmetic average and the weighted average. The weighted average was calculated by correcting the arithmetic average for relative quantity of crude throughput represented by the refineries reporting in a given category. All data are presented in terms of pounds of a particular contaminant per thousand barrels of crude oil throughput, for consistency and ease of comparison.

The range of data reported for various parameters and the spread in maximum and minimum values are undoubtedly due to many influencing factors, including--

TABLE 23

API REFINERY EFFLUENT SURVEY
SUMMARY OF WASTE LOADS, RANGE AND MEAN BY COMPLEXITY GROUPINGS
(Pounds per Thousand Barrels of Crude Oil Throughput)

Refinery Complexity Group	Type of Waste Treatment	BOD			COD			OIL			PHENOLS			SUSPENDED SOLIDS		
		Range	Mean	Weighted Average	Range	Mean	Weighted Average	Range	Mean	Weighted Average	Range	Mean	Weighted Average	Range	Mean	Weighted Average
A--Topping	Primary	6- 88	36	54	-	-	-	<1-84	16	29	<.01-3.5	0.9	<1	<1-101	26	57
	Intermediate	-	-	-	-	-	-	<1- 5	3	1	.01-1.1	0 6	<1	2-155	79	12
	Biological	-	-	-	-	-	-	-	-	-	.04-0.5	0.3	<1	-	-	-
B-- Topping & Cracking	Primary	<1-209	71	73	12-545	169	207	<1-154	33	25	0.1-59	11	13	<1-346	71	85
	Intermediate	26- 29	27	27	42- 79	57	58	<1- 6	4	5	.2- 2.1	1.1	1	10- 16	13	13
	Biological	<1-338	29	26	6-600	95	78	<1- 64	5	6	<.01- 8.6	1.0	<1	1-154	26	21
C--Topping & Cracking Plus Petrochemicals	Primary	5-350	116	111	10-234	124	115	3-292	57	45	.6- 5.6	2.6	2	10-350	70	42
	Intermediate	14- 83	42	43	56-144	99	109	2- 53	13	17	.3-21.6	7.5	6	<1- 56	18	21
	Biological	3- 61	33	34	27-209	97	96	4- 38	14	14	<.01- 7	1.8	2	3- 16	12	13
D--Integrated	Primary	32-258	122	147	77-1,481	383	216	4-222	53	67	1.2-44	7.4	10	<1-113	38	41
	Intermediate	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Biological	5-235	67	68	26- 649	168	159	<1-163	28	26	.01-13	2.5	4	4- 72	25	26
E--Integrated vPlus Petrochemicals	Primary	93-144	118	125	152- 366	259	288	7- 88	47	58	1.6- 9.5	5.6	7	34- 94	64	72
	Intermediate	76- 97	86	89	156- 395	276	245	8- 22	15	16	-	-	-	-	-	-
	Biological	65-168	115	108	204-1,055	675	706	28-132	66	72	1.4-10.9	6.2	6	87-150	117	119

Note: Decimals have been omitted, except for Phenols; mean waste load is arithmetic average of individual values.

Source: Elkin, Weil, Baum, Mann and Simonsen, "API Refinery Effluent Survey - Summary and Analysis" presented at Division of Refining Meeting, Philadelphia, May 16, 1968.

- Treatment goals and local requirements
- Extent of in-plant control
- Age of refinery
- Type of water utilization
- Extent of processing equipment and drainage system modernization
- Differences in crude oil characteristics
- Degree of housekeeping
- Efficiency of treatment facilities.

Data plots show that average values for most contaminants increase with increasing refinery complexity. Similarly, within a given complexity category, intermediate and biological waste-treatment procedures yield improved effluents, as would be expected. Points of significance disclosed by the survey data are the seemingly superior performance of intermediate treatments over biological treatments for the removal of oil and suspended solids.

4. Survey Limitations

The main objective was to assess the then current (1967) status of refinery effluents, and no in-depth attempt was made to define the following factors recognized to have an effect on any industrial effluent-quality survey:

- Discharge volume data was sometimes inadequate to calculate waste loads from analytical data.
- Biological treatment, as reported, covers a broad range of design and operating effectiveness and could well account for some effluent data scatter.
- No distinction was drawn between "old" and "new" refineries, although it is recognized that new plants incorporating modern processes and drainage systems can produce extremely clean effluents. It is less clear whether old refineries can be modernized and produce equivalent results.
- No strong effort was made to ensure consistency of analytical methods, but it is believed standard procedures were used in reporting all parameters except oil, for which alternate laboratory techniques are still in use.

Section 3.
ATMOSPHERIC POLLUTION CONTROL

The major potential refinery emissions which may contribute to air pollution are sulfur compounds, hydrocarbons, nitrogen oxides, particulates including smoke, and carbon monoxide. Other emissions of lesser importance are aldehydes, ammonia and organic acids. Table 24 illustrates the potential sources of the various contaminants from refineries and illustrates the variety of operations involved.

The character and quantity of refinery atmospheric emissions vary greatly from refinery to refinery. Controlling factors include crude oil capacity, type of crude oil, complexity of processing employed, air pollution control measures in use, and the degree of maintenance and good housekeeping procedures in force. The methods of controlling refinery emissions and estimating the quan-

TABLE 24

POTENTIAL SOURCES OF SPECIFIC EMISSIONS FROM OIL REFINERIES

Emission	Potential Sources
Sulfur Compounds	Boilers, process heaters, catalytic-cracking unit regenerators, treating units, H_2S flares, decoking operations.
Hydrocarbons	Loading facilities, turnarounds, sampling, storage tanks, waste-water separators, blowdown systems, catalyst regenerators, pumps, valves, blind changing, cooling towers, vacuum jets, barometric condensers, air-blowing, high-pressure equipment handling volatile hydrocarbons, process heaters, boilers, compressor engines.
Oxides of Nitrogen	Process heaters, boilers, compressor engines, catalyst regenerators, flares.
Particulate Matter	Catalyst regenerators, boilers, process heaters, decoking operations, incinerators.
Aldehydes	Catalyst regenerators.
Ammonia	Catalyst regenerators.
Odors	Treating units (air-blowing, steam-blowing), drains, tank vents, barometric condenser sumps, waste-water separators.
Carbon Monoxide	Catalyst regeneration, decoking, compressor engines, incinerators.

Source: U.S. Department of Health, Education and Welfare, *Atmospheric Emission from Petroleum Refineries, A Guide for Measurement and Control,* Publication No. 763 (HEW Public Health Service, 1960).

tity of emissions have been well established, especially in the Los Angeles area, through the cooperative efforts of the petroleum industry and regulatory agencies. The combined quantity of emissions to the atmosphere from all Los Angeles area refineries has been studied extensively and reported periodically.[245] Although similar in-depth studies for all United States refineries have not been completed, various estimates have been completed with sufficient accuracy to establish the relative magnitude of refinery emissions as compared with the total of the principal atmospheric pollutants in the United States. Estimated refinery emissions and the national totals reported by the National Academy of Sciences are given in Table 25.

The tabulation in Table 25 is based on limited data and should be viewed as only a useful approximation.* This limitation on the use of the Table applies particularly to the carbon monoxide emissions estimate from refineries, which exceeds the value reported for all industrial sources by the National Academy of Sciences.[246] While Table 25 indicates that refineries contribute a small fraction of the total principal pollutants in the United States, the contribution from refineries within a particular community may be a much larger factor.

Refinery air pollution control techniques have been developed which should permit refineries to operate in any community without constituting an air pollution problem. In fact, application of the techniques described in the following

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*Other sources, while generally agreeing with the refinery emissions figures, variously report total U.S. emissions up to twice those reported by the NAS.

TABLE 25

PRINCIPAL ATMOSPHERIC POLLUTANTS IN THE UNITED STATES

Type	Emissions from All Sources* (Million Tons/Year)	Refinery Emissions (Million Tons/Year)
Carbon Monoxide	65	4.00
Oxides of Sulfur	23†	1.60
Hydrocarbons	15	1.80
Particulate Matter	12	0.13
Oxides of Nitrogen	8	0.33
Other Gases and Vapors	2	--
TOTAL	125	

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* Source: National Academy of Sciences, *Waste Management and Control*, Publication 1400 (Washington, D.C., National Academy of Sciences, 1966) p. 11.

† Reported as 28 million tons per year in HEW's *Control Techniques for Sulfur Oxide Air Pollutants*.

sections has permitted operation of several major refineries in the Los Angeles area without contributing significantly to the air environmental problem.

The ability of refineries to keep air emissions to a small fraction of the emissions in an urban community is illustrated in the following tabulations of data (Tables 26, 27) for the year 1968, by the Los Angeles County Air Pollution Control District.[247]

Note that while the percent of sulfur dioxide emissions indicated in Table 27 appears relatively high, the total amount of sulfur dioxide shown in Table 26 is less than 10 to 15 percent of that in other cities.

Judgment of the adequacy of technology for pollution abatement for petroleum refineries, of course, is based on the present understanding of the requirements for acceptable air environment in the Nation's communities. Future developments in the science of air quality could require further development of refinery emissions control techniques.

While techniques of emissions control may be adequate to prevent areawide air environmental problems, refineries have not yet achieved the goal of being "unseen, unheard and unsmelled." Tremendous progress has been made but continued efforts are required to achieve complete aesthetic and psychological acceptance by residential areas immediately adjacent to refineries.

The main opportunities for refinery emissions occur during combustion, such as in providing power and heat for processing operations. These instances include combustion of fuel in boilers for steam generation, combustion of fuel in process heaters, and combustion of carbon during regeneration of cracking catalyst. The combustion of fuel in boilers and process heaters poses general problems (not specifically related to refineries), such as the presence in the combustion stack gas of sulfur oxides and particulates which relate to the quality of the fuel burned. The combustion of carbon from a catalyst is not unique to the petroleum industry, but it produces special problems, such as the formation of carbon monoxide and the entrainment of small catalyst fragments.

Potential refinery emissions and techniques for their control are described in the following paragraphs. These emissions, in order of discussion, are: sulfur compounds; hydrocarbons; particulate matter, smoke and oxides of nitrogen; and odors.

TABLE 26

CONTAMINANTS FROM MAJOR SOURCES WITHIN LOS ANGELES COUNTY
(Tons per Day)

Major Source	Organic Gases: High Reactivity*	Organic Gases: Total	Particulates	NO_x	SO_2	CO
Petroleum Refineries†	5	50	4	25	55	30
Petroleum Marketing/ Production	50	170	--	20	--	--
Motor Vehicles	1,255	1,730	45	645	30	9,470
All Other	145	600	61	260	140	195
TOTAL	1,455	2,550	110	950	225	9,695

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* A hydrocarbon with high reactivity is one which reacts readily with nitrogen oxides to form photochemical smog.

† Refining capacity approximately 730,000 barrels per day.

Source: *Profile of Air Pollution Control in Los Angeles County* (Air Pollution Control District, County of Los Angeles, Calif., January 1969).

TABLE 27

REFINERY EMISSIONS COMPARED WITH TOTAL OF MAJOR SOURCES IN LOS ANGELES COUNTY

Type	Refinery Emissions (Percent of Total)
Organic Gases	
High Reactivity	0.3
Total	2.0
Particulates	3.6
NO_x	2.6
SO_2	24.4
CO	0.3

Source: *Profile of Air Pollution Control in Los Angeles County.*

A. Sulfur Compounds

Sulfur dioxide and traces of other sulfur compounds constitute major refinery emissions unless available control techniques are employed. United States Government studies have estimated that U.S. refineries emitted 1.6 and 2.1 million tons of sulfur dioxide in 1966 and 1968, respectively, maintaining about a 6-percent share of the total sulfur dioxide emissions from all sources in the United States in those years.

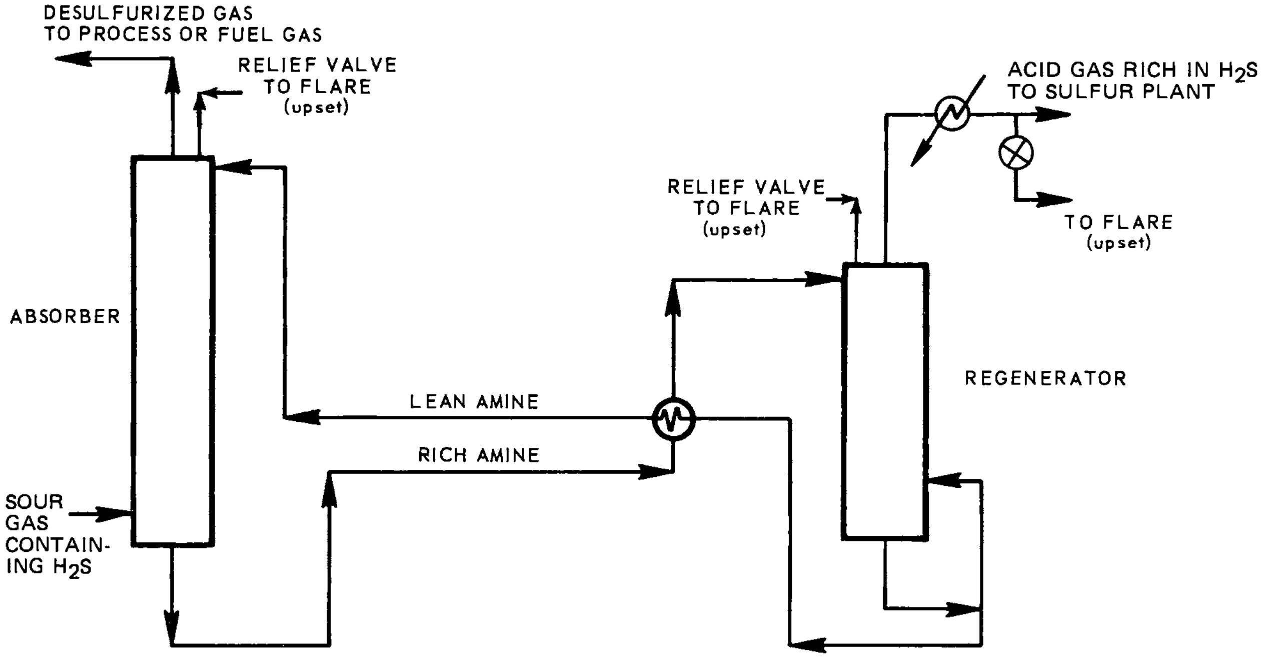
The major potential sources of sulfur oxide emissions from refineries are: (1) sulfur compounds contained in gases generated in refining processes which are used as fuel in process heaters and boilers; (2) use of residual fuel oil; (3) catalyst regeneration; (4) incineration of wastes such as sulfuric acid sludges; and (5) production and combustion of coke. Control procedures for most of these emissions have been developed since World War II as new refining techniques increased the potential for sulfurous emissions.

1. Control of Emissions from Refinery Process Gases

An API-sponsored study in 1966 reported that crude oil processed in the United States contained on the average approximately 0.76-percent weight sulfur, or approximately 3.8 million short tons of sulfur in the year, and total products manufactured from this crude oil contained only 30 percent, or approximately 1.1 million short tons of the original sulfur.[248] On this basis, the United States refineries had approximately 2.7 million tons of sulfur per year for disposal.

Nearly all refinery processes generate some gases which contain hydrogen sulfide or other low-molecular-weight sulfur compounds. These gases, after processing to remove valuable components, are used as fuel in process heaters and boilers. However, sulfur oxide emissions will result if sulfur compounds are not removed. Techniques are available and employed for the removal of all but a trace of hydrogen sulfide in the gases utilized as fuel.

The most common procedure involves scrubbing the gases with an absorption agent, such as an aqueous amine solution. Figure 41 is a simplified flow chart of the regenerative process. Hydrocarbon gas rich in hydrogen sulfide enters the



Source: HEW, *Control Techniques for Sulfur Oxide Air Pollutants,* NAPCA Publication No. AP-52 (Public Health Service, Consumer Protection and Environmental Health Service, Jan. '69), p. 77.

Figure 41. Flow Chart for H_2S Removal by Amine Solutions.

bottom of an absorber column and the lean amine solution enters at the top and contacts the gas countercurrently. The amine solution rich in hydrogen sulfide is regenerated by stripping the hydrogen sulfide with heat and/or steam. The amine solution is then returned to the absorber. Hydrogen sulfide from the regenerator is cooled and can be converted to either sulfuric acid or elemental sulfur.

A simplified flow diagram for collection and treatment of all process gases in a major refinery is shown in Figure 42. It should be noted that many relatively small sources of sour gas from crude distillation or vacuum distillation units are generated at low pressure and require compression for recovery and treatment. Venting of these gases to flares is normally acceptable.

2. Control of Emissions from Combustion of Residual Fuel Oils

Combustion of residual fuel oils in process heaters and boilers can be a significant source of sulfur oxide. Approximately 10 percent of the fuel used in 1968 in U.S. refineries was residual fuel oils.[249] This was equivalent to 39.9 million barrels of residual fuel oil, and at an estimated 1.75-percent weight sulfur, the emissions of sulfur dioxide would be 200,000 tons per year.

The refining industry is confronted with the same difficulties in controlling emissions of sulfur oxides from the burning of residual fuel oil in stationary combustion units as other industries burning sulfur-containing fuels. Processes for removing sulfur oxides from stack gases are only in the developmental phase.[250]

The problem of sulfur dioxide emissions from residual fuel oil combustion in refineries may become more difficult in the future. Customer demand for low-sulfur fuel oil is increasing, at the same time that sulfur content of the residual fuel oil is also increasing as refineries convert more of the "bottom of the barrel" to products in higher demand, such as distillates and gasoline. The average sulfur content of all residual fuel oil produced in the United States increased from 1.2 percent in 1950 to 1.75 percent in 1968, while the yield decreased from 20 to 8 percent of the crude oil processed.[251] As a result, economic considerations should result in a greater proportion of residual fuels being consumed as refinery fuels.

Processes are now being developed which will convert all residuals to distillates and lighter products with procedures that permit removal of essentially all of the sulfur compounds. An example would be a gasification process, such as partial oxidation. In this process, heavy residues could be converted to light gases, in the course of which sulfur is converted to a form that can be readily removed.

3. Control of Emissions from Catalyst Regeneration

Regeneration of a catalytic-cracking catalyst by controlled combustion produces small amounts of sulfur oxides as a result of sulfur compounds present in the coke which deactivated the catalyst. The quantity of sulfur is dependent upon the type of feedstock and method of operation.

A procedure for the removal of sulfur dioxide from catalytic-cracking flue gases has not been developed. However, sulfur oxide emissions are greatly reduced (by 75 to 80 percent) when the cracking unit feed is desulfurized by hydrogenation. Hydrotreating of the feedstock is done to improve the yield of high-demand products (mainly gasoline) rather than to control sulfur emissions. However, application of this process to cracking is expected to increase and should result in a major reduction in emissions.

4. Control of Emissions from Incineration of Acid Sludges and Miscellaneous Sources

Waste acids and sludges from acid treatment of products, and from other refinery processes such as alkylation, were frequently burned as a method of dis-

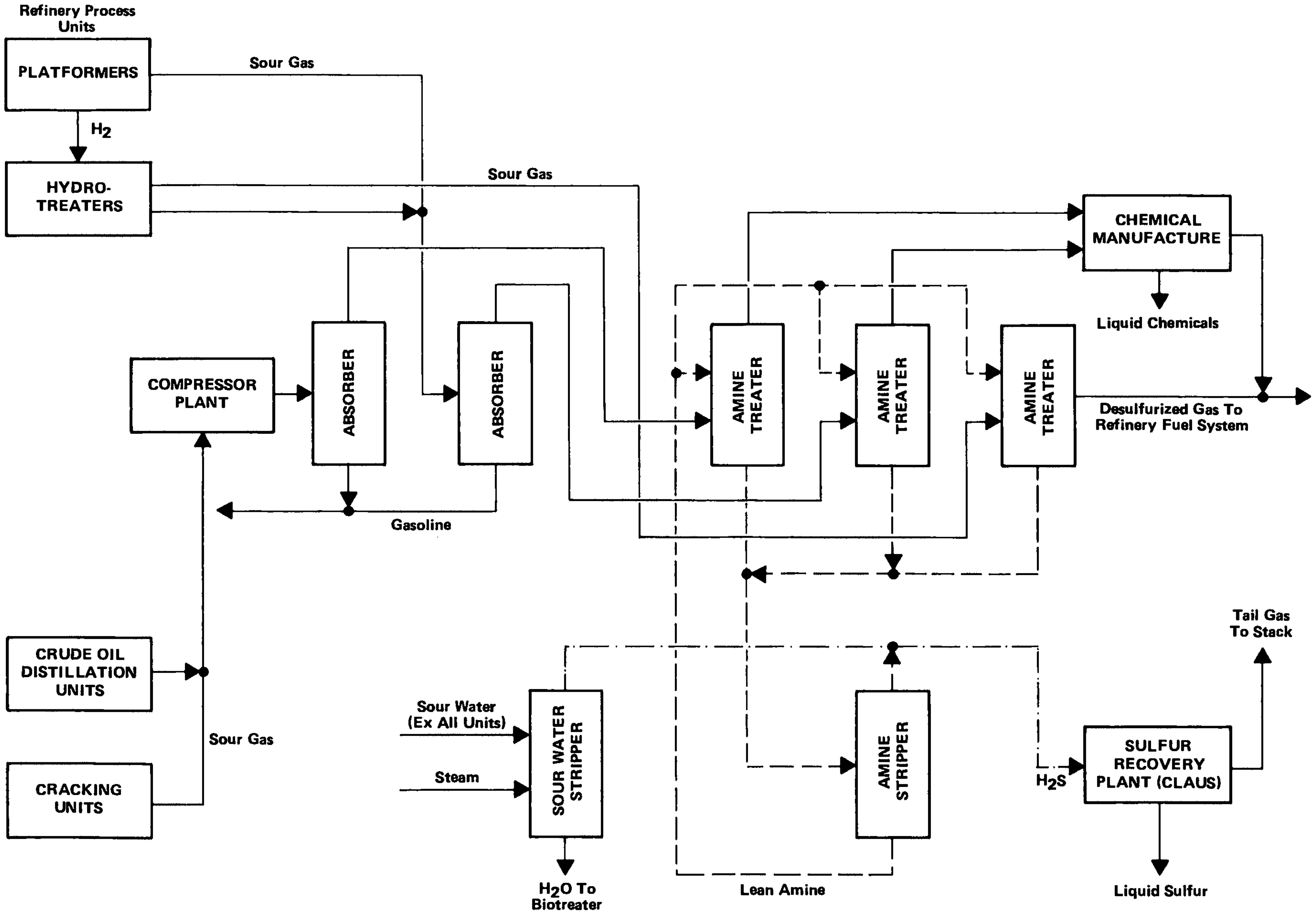


Figure 42. Simplified Flow Diagram of Sour Gas and Sulfur Recovery System.

posal in earlier years. This procedure produced large local concentrations of sulfur oxides and has been discontinued in most refineries. Modern treating processes, such as hydrotreating, have replaced treating processes which produced large quantities of acid sludges. Most of the waste acids and sludges which continue to be generated are reprocessed by acid manufacturing units for recovery of acid values, thereby avoiding disposal by burning.

Sour-water strippers are a potential source of sulfur dioxide emissions. Condensates, weak alkaline solutions and other aqueous solutions from refinery processes will normally be contaminated by hydrogen sulfide. Sulfides are very detrimental to natural waters and must be removed from refinery waste waters. The most common procedure is to collect the streams in a closed system and strip the hydrogen sulfide with steam. The stripped hydrogen sulfide can be processed in a sulfur-recovery system as shown in Figure 42. This procedure, however, is sometimes difficult because of contaminants, and some refineries occasionally dispose of the sulfide by burning in process furnaces or by burning for boiler heating.

Other processes have been developed to dispose of sulfide waters without sulfur dioxide emissions. These include the manufacture of ammonium sulfate fertilizers and a process for oxidizing the sulfides in the aqueous phase to thiosulfates.

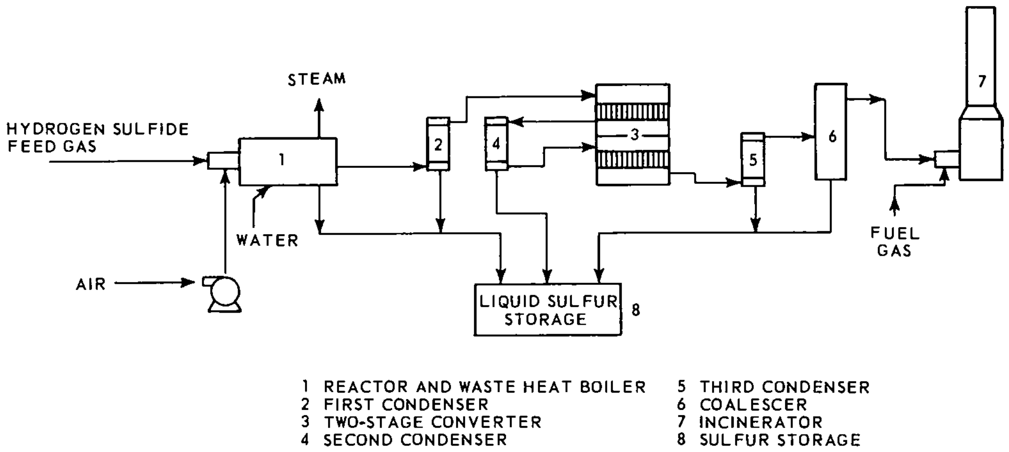
Very small emissions of sulfur dioxide may occur from such treating procedures as air-blowing asphalt and the subsequent burning of exhaust gas. However, the amounts of sulfur emitted in procedures such as this are usually measured in terms of a few pounds per day.

Hydrogen sulfide derived from the petroleum processes described earlier can be recovered as elemental sulfur with the Claus process or converted to sulfur trioxide over a catalyst bed then reacted with water to form sulfuric acid. The Claus process is the most widely used method of producing sulfur from refinery hydrogen sulfide, and is based on oxidation of approximately one-third of the hydrogen sulfide to sulfur dioxide, which is then reacted with the remaining hydrogen sulfide in the presence of a catalyst to produce elemental sulfur.

A typical process flow is shown in Figure 43. The acid gas enters a reaction furnace where approximately one-third is oxidized with a controlled volume of air. The reaction is exothermic, and heat is removed from the system by generation of steam in a waste-heat boiler. Some sulfur is formed in the initial reaction and is liquefied in the first condenser and drained to the liquid sulfur storage vessel. The remaining gases go to a catalytic converter where additional hydrogen sulfide and sulfur dioxide react to form sulfur and water. Two stages are used for more complete recovery. (For maximum efficiences of sulfur plants it is necessary to control the ratio of hydrogen sulfide to sulfur dioxide at 2:1.) Elemental sulfur is condensed in the second and third condensers and drained to the storage vessel. The remaining gases pass through a coalescer for removal of entrained sulfur droplets and are then incinerated to convert the remaining traces of sulfur to sulfur dioxide. The incinerator discharge is diluted with air before discharge into the atmosphere.

A two-stage sulfur plant is ordinarily capable of recovering 90 percent of the hydrogen sulfide as elemental sulfur; the remaining 10 percent is emitted from the incinerator stack as sulfur dioxide. A three-stage unit will normally recover 95 to 96 percent of the sulfur.

Although these units are major air conservation devices, their operation occasionally creates locally unsatisfactory conditions. Unsightly plumes may occur under certain meteorological conditions. In addition, the concentration of sulfur dioxide in the stack gas requires adequate dispersion to prevent unsatisfactory ground-level concentrations of sulfur dioxide in the immediate vicinity of the plant. New processes are being developed to remove sulfur dioxide from these sulfur-plant stack gases to meet stringent emissions regulations.



Source: HEW, *Control Techniques for Sulfur Oxide Air Pollutants*, p. 78.

Figure 43. Sulfur Recovery Plant (Flow Chart).

B. Hydrocarbons

Hydrocarbons are the products of a refinery, and there is an obvious economic incentive to prevent their loss to the atmosphere; therefore, many air pollution control measures are necessarily employed as accepted good practice.

The role played by hydrocarbons in the complex photochemical smog reaction was first postulated and extensively studied in the Los Angeles area in the 1950's. As a result, hydrocarbon-loss control in Los Angeles area refineries has been extensively studied and a high degree of containment achieved, which is unmatched in other refining areas.

Hydrocarbon emissions in amounts normally released by refinery operations are invisible and nontoxic. Detailed surveys in Los Angeles by regulatory agencies show that only 10 percent of the refinery hydrocarbon emissions have high reactivity whereas over 70 percent of the hydrocarbon emissions from automobiles are classified as having high reactivity.*

Hydrocarbon emissions from petroleum refineries may range from 0.1 to 0.6 weight percent of the crude oil processed.[252] The lower value is considered typical of Los Angeles refineries. Assuming an average value of about 0.25 weight percent for the total U.S. refinery capacity suggests a total refining industry emission of 1.8 million tons per year, which is approximately 12 percent of the total reported for all sources in the United States.[253]

Potential sources of hydrocarbon emissions are listed in Table 24 (p. 181); the techniques for their control are reviewed in the following sections.

1. Control in Storage Tanks

United States refineries have large storage tanks which could be a substantial source of emissions if control techniques were not utilized. For example, an 80,000-barrel "fixed" or "cone" roof tank filled 25 times in a year with gasoline would emit a calculated 3,000 barrels per year, or 8 barrels per day. These losses occur primarily from two factors: (1) Vapors are forced out when gasoline is pumped into the tank; and (2) as the temperature increases during

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*A hydrocarbon with high reactivity is one which reacts readily with nitrogen oxides to form photochemical smog.

the day, the vapor in the tank expands and vents to the atmosphere. The procedure is reversed during the night; thus, this daily "in-and-out" vapor flow is generally referred to as "breathing."

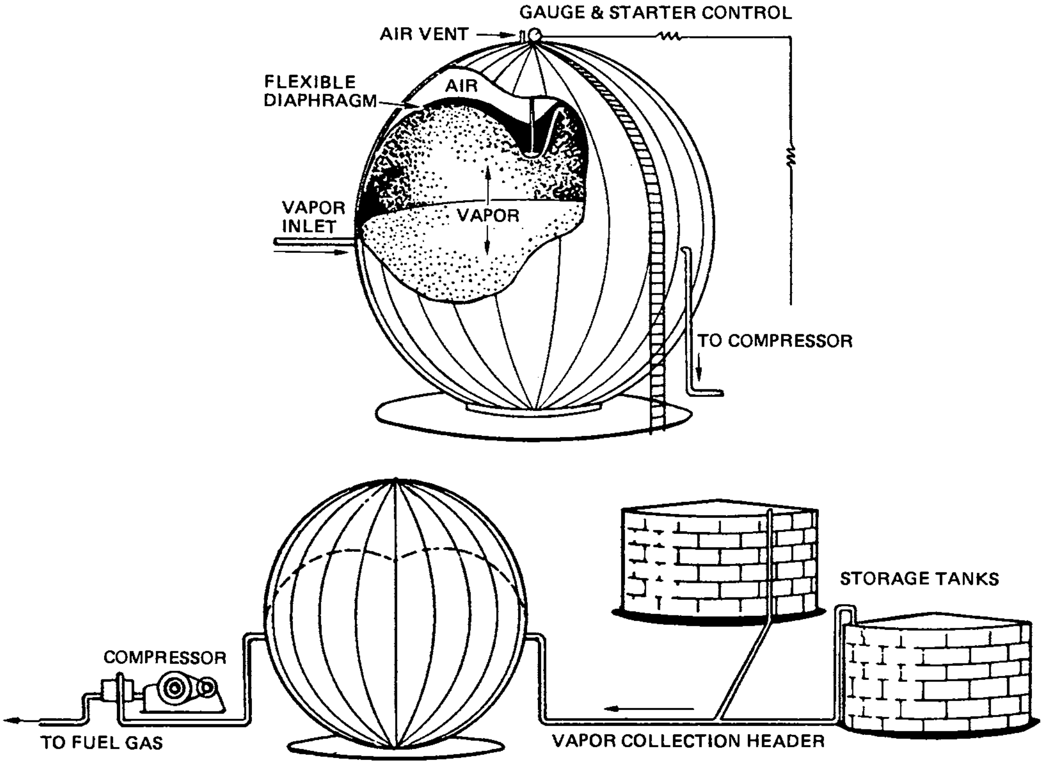
Emissions of hydrocarbon from tanks are controlled by (1) eliminating the vapor space in the tank by utilizing a "floating roof," (2) utilizing a variable vapor space to allow for changes in pressure and liquid level with excess volumes going to a vapor-recovery system, and (3) providing pressurized tanks for storing highly volatile hydrocarbons. Development of plastic foam blankets and internal light-weight floating covers may make conversion of conventional cone-roof storage to vapor-conservation storage more attractive.

The floating roof is simply a pontoon-type structure that moves up and down with the gasoline level. Although simple in principle, the engineering is complex. The system is explained in greater detail in Chapter Six, "Storage, Transportation and Marketing."

A variable-space sphere and vapor-recovery system are depicted in Figure 44. In one refinery installation, 22 fixed-roof tanks were connected to three "vapor spheres," each with a capacity of 150,000 cubic feet. A flexible hemispherical diaphragm, made of nylon and neoprene rubber, "floats" with changes in vapor-space volume in the tanks. If the vapor-space requirements exceed the capacity of the sphere, a compressor will automatically pump vapors to a recovery unit.

2. Control in Catalytic-Cracking Regenerators

Flue gas from catalytic-cracking regenerators is reported to have a concentration of 100 to 1,500 parts per million of hydrocarbons. It is estimated that fluid catalytic-cracking units in Los Angeles, with a fresh feed capacity of 156,000 barrels per day, emitted 17 tons per day of hydrocarbons.[254] However,



Source: HEW, *Air Pollution Control Field Operations Manual* (Public Health Service, 1962), p. 49.

Figure 44. Simplified Diagram of a Vapor-Recovery System.

these hydrocarbons are almost completely consumed when the cracking units are equipped with waste-heat boilers or heaters as described in a subsequent section.

3. Control in Waste-Water Separators

Waste-water gravity separators are used to trap and recover oil discharged to the waste-water system from equipment leaks, pump glands, sampling, shutdowns and process-condensate water. As the hydrocarbon-water mixture flows through the system, hydrocarbons evaporate and may escape to the atmosphere. If this loss is substantial and control is desirable, the waste-water separators may be equipped with covers; as shown in Figure 45. Losses can be further minimized by catch-basin liquid seals, manhole covers and good housekeeping practices. Emissions from process drains and from waste-water separators for all refineries in the Los Angeles area have been estimated to be 3 tons per day.

4. Control in Loading Operations

Although the major portion of products leaves refineries through pipelines with no emission to the atmosphere, loading into tank trucks, tank cars and ships can result in hydrocarbon loss by displacement of vapors and evaporation. Techniques for preventing these losses are described generally in Chapter Six.

The major portion of losses during loading operations, however, can be prevented by submerged filling devices. This technique simply involves locating the loading nozzle at the bottom of the receiving tank so that the incoming flow ejects below the surface of the liquid.

Los Angeles area regulations required a substantial development program to design equipment which would recover nearly all of the hydrocarbons during loading operations.

Photo: Courtesy of Tom Carroll—Photographic International Corp.

Figure 45. Refinery Oil-Water Separator with Floating-Roof Covers.

5. Control in Pumps and Compressors

Hydrocarbons can leak to the atmosphere between the moving shaft and stationary casing in pumps and compressors. The Los Angeles survey estimated that a centrifugal pump leaked an average of 3 to 5 pounds of hydrocarbon per day, and that approximately 6 tons of hydrocarbon per day were emitted to the atmosphere from these sources. This type of loss may also occur with a compressor. Leakage of heavy hydrocarbons ordinarily does not vaporize, while lighter hydrocarbons may.

Asbestos and other fibers can be packed around the shaft to retard leakage. Mechanical seals, consisting of two plates placed perpendicular to the shaft and forced tightly together, have been developed as a superior method of loss control. Wear can result in substantial losses from all such devices, and thorough inspection and maintenance practices are an essential part of a control program.

6. Control of Miscellaneous Sources

In complex refining units, other numerous, potential sources for small emissions exist which can easily be controlled at a satisfactory level. Pressure-relief valves can be manifolded to a flare system or, if vented to the atmosphere, routine observation and maintenance are adequate for control purposes to prevent leakage. Hydrocarbon fumes from air-blowing operations can be consumed by incineration in flares or furnaces. Steam-driven jets, employed to induce a vacuum in process equipment, may discharge small amounts of light hydrocarbons with the exhaust gases; these gases can be vented and burned in heater fireboxes.

Miscellaneous sources, such as leaking valves and pipe flanges, are readily controlled by periodic inspection and maintenance. Preventive maintenance programs which include good housekeeping techniques are essential in minimizing hydrocarbon emissions.

In summary, it can be said that adequate technology for measurement and control of hydrocarbon emissions from petroleum refineries is available. Joint efforts of the petroleum industry and the regulatory agencies in Los Angeles have resulted in extensive reporting of these methods of control.[255]

C. Other Emissions

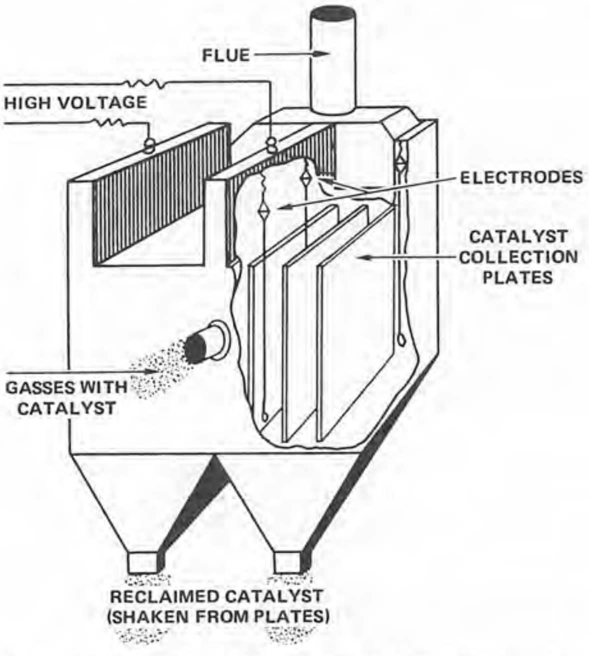
1. Particulate Matter

The major potential sources of particulate matter emissions in modern refineries are catalytic-cracking regenerators. Minor sources may be air-blown asphalt stills, sludge burners, boilers and emergency flares.

Fluidized catalyst is circulated through the reactor and regenerator. This catalyst is primarily silica and alumina, very similar in composition to naturally occurring clays and sand. Coke accumulates on the catalyst in the reactor and is removed by controlled combustion in the regenerator at approximately 1,200 degrees Fahrenheit in order to restore catalyst activity. In a major cracking unit, 100,000 to 150,000 cubic feet per minute of flue gas will be vented following oxidation of the catalyst, which may be circulating through the unit at the rate of 50 tons per minute.

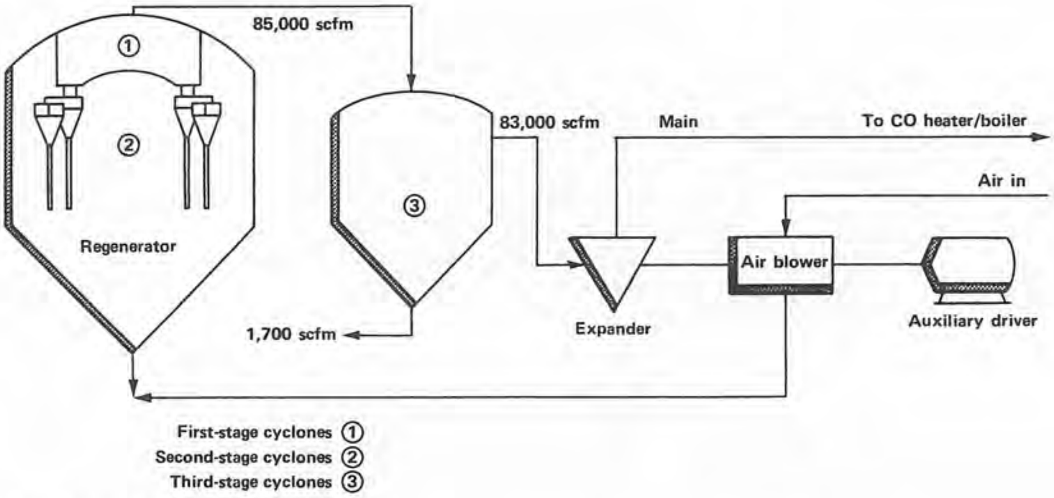
Normally, two-stage conventional cyclones are located within the regenerator vessel for catalyst recovery and recirculation. Catalyst dust entrained in the flue gas emanating from regenerators with two-stage internal cyclones may be in the order of 200 pounds per hour, depending on size, basis of design and the mechanical condition of the unit. This quantity is generally reduced by use of an additional cyclone or an electrostatic precipitator (Figure 46) which treats the flue gas before discharge to the atmosphere.

Third-stage cyclones of high efficiency have recently been installed in some refineries to enable economic recovery of energy from hot flue gases.[256] As shown in Figure 47, hot flue gases in exiting from the regenerator to the third-stage cyclone are passed through an expander-turbine which powers the air blower supplying air to the regenerator. High-efficiency removal of catalyst from the regenerator gases is essential since catalyst particles larger than 10 microns will erode the turbine blades. While the incentive for these systems has been the economic recovery of energy, the reduction in particulates emitted is also a benefit. A well-designed third-stage cyclone, or the alternative of an electrostatic precipitator, has efficiencies for recovering catalysts ranging up to 99.99 percent.



Source: HEW, *Air Pollution Control Field Operations Manual*, p. 46.

Figure 46. Diagram of Plate-Type Electrostatic Precipitator Used to Collect Catalyst Dust.



Source: *Oil & Gas Journal* (Mar. 24, 1969).

Figure 47. Typical Cyclone System, FCC Plant.

Other sources of particulate matter are minor in most refineries, and satisfactory control methods or alternative procedures have been developed to control these sources. Air blowing of asphalt, as practiced in some refineries, generates oil and tar mists which are controlled by water scrubbing and/or incineration. Burning of oil sludges containing heavy petroleum residues and inorganic material, such as clay and sand, can be a source of particulates. These sludges are usually small in volume, and alternative methods of disposal can be devised without producing a significant emission of particulates. Such methods include landfill (in which the oil residues are biologically decomposed), solvent extraction or disposal at sea.

2. Smoke

Possible sources of smoke in refinery operations may be classified in three general categories: (1) process furnaces and boilers, (2) vent gas flares and (3) incinerators.

Furnaces and heaters should not be a source of undesirable levels of smoke. Approximately 80 percent of the fuel utilized in the petroleum industry is natural gas, or the equivalent refinery gas manufactured in various processes, which is easily utilized without production of smoke. Whenever liquid fuels such as residual fuel oils are burned, adequate and relatively inexpensive equipment is available to prevent all but a minimal amount of smoke with good operating practices and maintenance.

Waste-gas vent flares can be a major source of smoke. Flares are necessary as a safety measure to handle unexpected losses of vapor. Refining facilities produce relatively large volumes of hydrocarbon gases. Although economic considerations require that any steady production of gas be sold or used within the refinery, large quantities of gas may be released from process units in emergencies caused by compressor failure, excessive pressure in the units, line breaks or leaks, power failure or fires. Since the large surges of gas cannot be vented to furnaces or other enclosed burning equipment, waste-gas vent flows are designed to safely dispose of these gases.

Smoke from these flares results from an inadequate supply of air in the combustion zone. The large flow of gas to a flare requires more energy to mix adequate air with the gas than is naturally available. Several techniques have been developed that virtually eliminate smoke, the most widely used being injection of large quantities of steam into the combustion zone with uniquely designed flare tips.

Disposal of small quantities of oily wastes and sludges has been a continuing problem for refinery operations. The simplest method of disposal has been accumulation and periodic burning which has frequently produced large quantities of smoke. Development of new treating processes, such as hydrotreating, has greatly reduced the production of waste-chemical sludges. In addition, alternative methods of disposal have been found which make it possible for most refineries to avoid burning them or to burn materials in a smokeless manner. Procedures are discussed in the American Petroleum Institute *Manual on Disposal of Refinery Wastes, Volume on Liquid Wastes, 1969.*

In summary, adequate technology is available for refineries to operate without the generation of smoke except for more than a few minutes at very infrequent intervals.

3. Oxides of Nitrogen

The major source of oxides of nitrogen in a refinery is from combustion of fuels in the various process heaters and boilers. Other sources are relatively few internal-combustion engines (such as drivers for compressors), flares, and flue gases from catalytic-cracking regeneration. These latter sources should cause less than 10 percent of the total refinery emission of nitrogen oxides.

Refinery stack-gas streams from combustion of fuels have low concentrations of nitrogen oxides which are not a significant problem under normal circumstances.[257]

The contribution of refinery emissions to the national emission of oxides of nitrogen has been estimated to be less than 10 percent.[258] An extensive study of 1968 emissions in the Los Angeles area, which has a large concentration of refineries (approximately 730,000 barrels per day capacity, or almost 7 percent of the national total at that time), indicates that refinery oxides of nitrogen emissions are relatively minor compared to other sources in an urban commuity.[259] The Los Angeles study states that the petroleum refineries emitted only 25 tons per day of nitrogen oxides, or approximately 2.6 percent of the total of 950 tons per day from all sources in the Los Angeles basin.

If control of nitrogen oxides from all stationary sources becomes mandatory, the control problem for the refining industry will be the same as that confronting all stationary users of gaseous or liquid fuels.

4. Carbon Monoxide

The only significant source of carbon monoxide emissions in petroleum refineries is the catalytic-cracking regenerator. Concentrations of carbon monoxide in regenerator flue gases may be in the range of 6 to 10 percent. These flue gases are generally released high in the air and at high temperatures, resulting in very low ground-level concentrations.

Carbon monoxide emissions from catalytic-cracking units can be eliminated by incinerating the gases in waste-heat boilers or heaters at temperatures of 1,500 to 2,000 degrees Fahrenheit. The heat of combustion of the carbon monoxide and other combustibles and the sensible heat of the regenerator gas are recovered by generating steam or heating the oil charged to the cracking unit. The carbon monoxide is completely oxidized to carbon dioxide; in addition, traces of aldehydes, hydrocarbons and cyanides are destroyed.

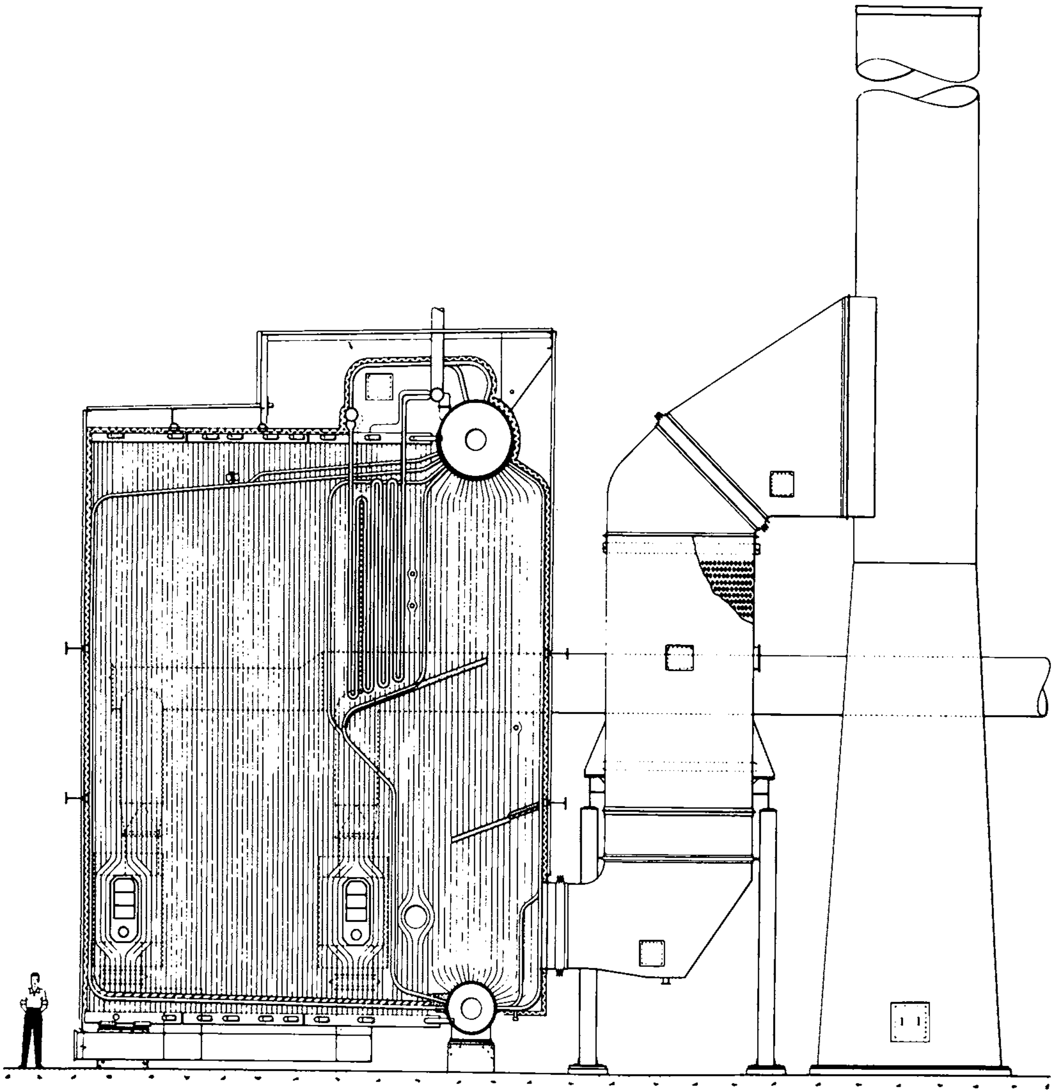
Carbon monoxide boilers were originally developed as a means of improving the cost-efficiency of the catalytic-cracking process. Air pollution control is also a benefit. Essentially all major catalytic-cracking units constructed in recent years have been equipped with carbon monoxide boilers or heaters (Figure 48). Numerous existing catalytic-cracking units have been equipped with carbon monoxide boilers on a profitable basis.

A detailed survey of the number of carbon monoxide heaters and boilers installed in the United States is not available, but it is believed that more than 50 percent of the major refineries have these installations. The Los Angeles Air Pollution Control District has reported that carbon monoxide boilers have prevented the emission of 1,600 tons per day of carbon monoxide from Los Angeles refineries. This represents essentially 98-percent elimination of the potential refinery carbon monoxide emissions. The remaining estimated 30 tons per day of carbon monoxide from refineries represent 0.3 percent of the total of nearly 10,000 tons per day of carbon monoxide emissions in the Los Angeles basin.

D. Odors and Miscellaneous

Odors associated with minor releases of unusual compounds are probably the most perplexing problems associated with refinery operations. Some of the malodorous compounds are perceptible at concentrations as low as a fraction of a part per billion. As a result, extremely small concentrations well below toxic or harmful levels cause complaints from nearby residents. The volume associated with odors is too small to be a significant weight percent of overall emissions to the atmosphere, and these odorous compounds are usually destroyed by oxidation after a short time in the atmosphere.

Odorous gases associated with petroleum refining are hydrogen sulfide, mercaptans, phenolic compounds, naphthenic acids, organic sulfides, nitrogen bases,



Source: HEW, *Control Techniques for Carbon Monoxide Emissions from Stationary Sources*, NAPCA Publication No. AP-65 (Public Health Service, March 1970), p. 4-11.

Figure 48. Water-Cooled, Carbon Monoxide Waste-Heat Boiler.

aldehydes and ammonia. These compounds occur naturally in crude oils or are formed during cracking or treating operations. These compounds can be emitted to the atmosphere from air or steam blowing in treating units, barometric condenser sumps, drainage of liquids from various process units, tanks, vents, and miscellaneous leakage in packing glands in pumps, compressors and valves.

Odors from air blowing of special products and similar operations are simply controlled by incineration of the gases in flares or furnaces. Steam condensates and other aqueous solutions containing malodorous compounds are collected in closed systems and stripped with air, flue gas or steam. The stripped malodorous gases are burned in furnaces or flares. If these gases contain substantial quantities of hydrogen sulfide, the sulfur may be recovered in a Claus unit, as described earlier. Barometric condensers are being replaced with more modern surface condensers, and the noncondensables may be burned in process heaters or in a separate incinerator.

The increased usage of hydrogen treating in place of chemical treating (such as acid and caustic treating) is simplifying the nuisance problem of malodorous compounds. Hydrogen treating destroys most of these foul compounds and converts them to more desirable products and hydrogen sulfide. Hydrogen sulfide can then be recovered as discussed in an earlier section.

A major problem in control of malodorous compounds is the prevention of even extremely small amounts of leakage from equipment such as pumps, valves and compressors. Good maintenance and operating practices must be employed to control these odors. If a refinery is to be maintained essentially odor-free, the development of improved equipment may be necessary.

Section 4.
LIGHT AND NOISE

A. Light

Light associated with the operation of refineries which can be observed from outside the plant originates from two principal sources. One of these involves the permanent facilities required for general nighttime illumination to permit safe and efficient operation of the facility. The other major source is the flame from combustion of waste gases in refinery flares.

Because of the large areas involved, the size and height of the structures and the fact that most facilities are located out-of-doors, oil refineries convey an impression of brilliant illumination, especially when observed from a distance. In reality, illumination within the plant is quite low. For example, lighting intensity for a typical refinery outdoor process area would average about 5 footcandles. In certain remote tank-storage areas, the level may be as low as 0.1 footcandle. Although levels are sometimes higher, especially when facilities are new, these values represent about the minimum for satisfactory surveillance of equipment by operating personnel.

On the basis of complaints by the general public, it does not appear that the average citizen finds the light provided for general illumination of refineries to be particularly objectionable. This is probably explained by the fact that modern society is conditioned to brilliant illumination associated with many types of commercial facilities, freeways and some industry.

The foregoing conclusion may not necessarily apply if a refinery were installed in the vicinity of a residential community unaccustomed to bright lights. In such cases, it should be possible to avoid a problem by careful attention to placement of storage areas, parking lots and similar facilities where minimum lighting would suffice. Location of such facilities around the periphery would tend to shield light emitted from the more highly illuminated process areas. Also, lighting of elevated structures might have to be subdued or eliminated.

Light produced by refinery flares is quite unlike that associated with general illumination. The major difference relates to the fact that the light emanates from a flame rather than a light fixture and can vary greatly in intensity and appearance, depending on factors such as size of flame, properties of gas, and whether or not steam is being introduced to avoid smoke.

During normal refinery operations, the flame is so small in size that the effect on overall illumination is negligible. However, when starting up or shutting down plants, or when process upsets occur, the venting rate to the flare will increase suddenly, with a pronounced increase in size of the flame and accompanying light. If releases of this type occur frequently and the flare is located near a residential area, the light may prove a source of annoyance to some people. The injection of excessive steam on flares, where steam is used for smokeless burning, may in some cases produce a flame of such low luminosity that it will not be objectionable when flaring at low-to-moderate rates. However, this technique has limitations due to an increase in noise associated with the use of excess steam. Thus it usually is feasible only where the flare can be located sufficiently remote from property lines that noise would not constitute a problem.

Where the aforementioned approach is not feasible, an alternate solution involves burning the waste gas inside a large vertical chamber constructed of suitable material to withstand the high temperature. An enclosure, 30 feet in diameter by 40 feet in height, can conceal flame from combustion up to about 50,000 pounds per hour of a typical refinery waste gas.

Although enclosing a flame is a practical approach for concealing flare light during routine venting and certain minor upsets, it is not feasible to shield the flame when peak loads occur during major emergencies and flames 300 feet or more in length are produced. The resultant light may cause a very pronounced increase in the background levels for a distance of several hundred feet. If elevated, the flame may be visible for miles. Because emergencies of this type occur so rarely, the increase in illumination has not been a serious problem, except where flares are located near the property lines. To avoid these situations, it is a good policy to situate flares well away from residential areas or other locations where they are exposed to the public.

B. Noise

In recent years, both the public and government authorities have been increasingly concerned over the intensified levels of noise from sources such as aircraft, highway traffic and industry. Views of various experts on the detrimental effects of noise on man are being reported with increased frequency.

Oil refineries are contributors to the noise problem, and the industry has been actively engaged in recent years in programs to reduce refinery noise levels. Problems associated with excessive refinery noise can be classified as those involving employees and those affecting the adjacent community.

From the standpoint of employees, noise may be of concern for reasons of potential damage to hearing, interference with oral communications, and because of psychological effects which impair efficiency. Although hearing damage is of most importance, the other two problems mentioned can be of major significance in the operation of a refinery.

With reference to the effect of refinery noise emissions on the community, the problem is essentially one of annoyance. The extent of annoyance is influenced by several factors such as the intensity and frequency of the noise; whether the noise is intermittent; whether the surrounding area is residential, industrial or some combination thereof; the community's attitude toward industry; and especially what an individual is doing at the time of exposure to noise. The latter condition is most important with regard to nighttime noises which affect sleep. In this connection, interference with sleep is especially significant insofar as refinery noise is concerned. For while many noise sources disappear or decrease at night, refinery noise usually remains at nearly the same level.

What constitutes excessive noise will depend on whether exposure involves refinery employees or residents of the community. In contrast to the fairly definitive guidelines which exist under the Walsh-Healey Act for employee exposure to noise,[260] establishment of a community noise criteria is essentially a matter of subjective judgment, because of the many factors involved. Thus each situation usually requires special consideration.

1. Noise Sources

The major noise sources in oil refineries can be classified into four general categories: (1) noise produced by moving fluids confined within the process system, (2) noise produced by high-velocity jets of gas or vapor discharging to atmosphere, (3) noise produced by mechanical equipment and (4) noise produced by combustion processes.

The noise associated with fluid movement originates from severe turbulence or vibratory impulses which may stem from many sources. These include high-velocity flow through pipes, abrupt changes in size of piping or direction of flow, passage through a compressor, pressure reduction at control valves, and so forth. The mechanism of noise formation and transmission associated with fluid turbulence is very complex, but the circumstances conducive to excessive noise from this source are sufficiently well understood that, in many cases, problems can be avoided by careful attention to design of piping system and selection of specialized equipment.

Noise associated with atmospheric vents usually relates to disposal of steam, air, nitrogen or other nonpollutant gases or vapors in conjunction with start-up, shutdown or regeneration processes essential to operation of refinery units. The sound generated results from turbulence produced in the boundary between the jet and the surrounding atmosphere and is primarily a function of the velocity. Noise from atmospheric vents is frequently a source of community noise problems. Control of noise involves limiting velocity and/or provision of silencers. The latter method is highly effective.

Several types of mechanical equipment widely utilized in refineries can be sources of excessive noise. These include electric motors, steam or gas turbines, compressors, blowers, gear boxes and air coolers. With the exception of air coolers, most of the noise generated by mechanical equipment is usually only a problem within the refinery and seldom disturbs the community. The source of the noise from mechanical equipment and methods of attenuation differ significantly for various types of mechanical equipment. Industry has come to rely heavily on suppliers to incorporate special features in design of equipment where high noise levels would create a problem.

The final source of refinery noise, the combustion process, involves two distinct types of equipment: furnaces or boilers, and refinery flares. Noise generated by flame turbulence is a characteristic of both furnaces and flares. In the case of a furnace, intense turbulence is required to provide efficient combustion and satisfy heat requirements of the process. Turbulence in flares, noted earlier, is a result of the introduction of steam into the flame zone to prevent smoke. Other sources of noise associated with combustion processes include premixing of air and fuel on gas-filled furnaces, and discharge of high-velocity steam to atmosphere from jets to provide smokeless burning of flare facilities.

Furnaces have been a major noise problem from a standpoint of both in-plant and community noise, the latter being dependent on how close the furnace is to property lines. Flare noise is essentially a community problem, since the noise usually originates from a location sufficiently remote from where employees conduct their activities that noise levels will not be excessive in terms of a hearing-conservation criteria. Reduction of noise from combustion processes has posed a difficult problem for the industry, but progress is being made as a result of cooperative efforts between refineries and suppliers.

2. Noise Abatement

As indicated above, there are many sources of noise inherent to the process of refining oil. Approaches to noise abatement vary widely, depending on such things as whether the problem affects employees or the community, the source and characteristics of the noise, and whether the facility involved is new or existing.

On new plants, noise abatement begins with the selection of quiet equipment. In many cases, manufacturers can reduce the noise at the source with special attention to equipment design. In addition to purchase of quiet equipment, there is usually sufficient flexibility in the layout and arrangement of facilities to allow higher noise sources to be located remote from the community, or to take advantage of shielding provided by other facilities.

On existing plants, noise abatement usually involves special acoustical treatment at the source. In situations where this approach is not practical, replacement of modifications or installation of silencers, etc., may provide a feasible solution. With the current state of technology related to noise control and abatement, it should be possible in most cases to design new refinery facilities to ensure an acceptable environment for employees, and not increase background levels in the adjacent community so as to constitute a nuisance. Noise abatement on existing facilities is more difficult and apt to be quite costly. Although it may not be feasible to reduce sound levels to those obtained on new plants, many noise sources can be attenuated to a point that there will be a noteworthy improvement both within and outside the refinery.

Section 5.
GENERAL CONTROLS

There are a number of good practices in the operation and design of a refinery which serve generally to reduce capital expenditures in the long run while, at the same time, directly improving the control of environmental pollution.

A. Operating Practices

Good maintenance practice is high on the list of good operating practices. For example, personnel are required to follow specific cleanup and maintenance rules. All pipelines are painted with anticorrosive materials. Pipelines, towers and tanks are inspected regularly and periodically to detect existing and potential leakage sources. During inspection or turnaround periods, pipelines are subjected to nondestructive testing to check thickness requirements and spot potential weak spots. Pressure vessels are also periodically inspected under mandatory maintenance procedures. Major pitting and corrosion are chemically treated or manually repaired to prevent damage or accidents. Incidents of excessive spillage are rare because of long-standing preventive maintenance programs.

Changes in prior maintenance practices have also brought about environmental improvements. Most refineries currently remove old equipment and old machinery and parts from the premises. Under past practices, such equipment was kept around to replace parts in newer equipment.

Most construction debris--such as wood and lumber--can be burned without smoke entering the atmosphere, in special combustion chambers that inhibit air pollution. Other operating practices of importance with respect to environmental conservation include the conservation of materials and training.

Refineries make extensive use of recycled materials. As water reuse, particularly for cooling purposes, continues to expand, raw-water requirements per barrel of crude will, on the average, continue to decrease. As another conservation measure, correct storage and maintenance procedures prevent processing materials from washing away into the ground. For example, granular sulfur is sprayed with resins or inert binders to seal its surface.

Refinery personnel receive regular training and periodic retraining in handling emergencies such as fires or pipe and tank ruptures. At some sites, simulated emergencies are enacted once a month to quicken the responses of personnel.

About 10 to 15 percent of refinery personnel are graduate engineers. Many of these engineers have rotated in various operating capacities and thus are extremely familiar with antipollution measures. At refineries, many such specialists, assisted by outside consultants from universities, supervise critical-path planning to facilitate production scheduling and thereby minimize accidents that may lead to pollution.

B. Design Practices

A number of examples of the design of specific items and of the overall plant can be cited which, though seemingly unrelated, have an effect on the prevention and control of pollution.

At refineries, noncorrosive material for pipelines and pumps are favored and cast iron is seldom, if ever, used because of its inherent brittleness. Pipelines into refineries have, in many plants, insulating flanges that inhibit electrolytic currents which cause corrosion. Pipelines for corrosive materials are made of stainless or alloy steels. Most operating companies paint tanks and structures light pastel colors. This protects the tanks against corrosion and reduces evaporation losses, as well as improving their appearance.

Tailoring production materials so they have less pollution potential is an important facet of refinery operations. Newly developed catalysts, for example, emit far less particles into the atmosphere. Refineries are also laying more stress on continuous monitoring of processing with sophisticated automatic instrumentation that reduces the likelihood of breakdowns within the system.

Design problems associated with plant layout are important factors affecting both the efficiency of overall operations and environmental conservation. In the latter respect they are particularly applicable to control of land and water pollution.

Therefore, selections of these factors have been discussed in various portions of Section 2B, "Waste Control Methods."

From the point of view of plant layout, the topography is most important for drainage. For this reason, the industry constantly seeks to better grade its refinery sites to avoid low spots that pool or impound oily wastes. By stressing correct grading, the industry is accelerating proper drainage into channels and sewer pipes. This eliminates the accumulation of oil and spent chemicals that otherwise might seep into the ground.

Surface wastes, as previously described, are adequately handled by a modern refinery disposal and catchbasin system. Emergency water-handling or impounding basins to handle excess rain or runoff from firefighting hoses are often provided. Surface drainage systems can be temporarily diverted to these basins when rainfall has been heavy. This prevents flooding or overflowing, which might carry oily wastes into the ground or water outside the refinery site.

Most newer refineries have concrete or blacktop processing and operating areas to prevent oily waste-water and oil drips from valves, fittings and other equipment from leaking into the ground and becoming a source of land pollution. At least 50 percent of the processing areas in most new refineries are paved.

Also, present-day refineries have aboveground piping, with the exception of water lines, to ease maintenance, reduce underground damage during excavations, and prevent ground pollution. Deep burial of water systems that provide fire protection prevents freezing and entails few, if any, corrosion problems; if such problems exist, effective precautions can be employed.

Tank storage areas are surrounded by dikes and levees to contain the contents of a tank if it should rupture or overflow. A small collecting basin inside the tank block area routes rainfall, which may include some oil, into the refinery sewer system rather than letting it seep into the ground. The industry is also stressing the development of the grounds of new refineries so that they will be more environmentally and aesthetically compatible with surrounding land areas. Around many sites, bushes and cover plants protect against ground erosion.

Chapter Six

STORAGE, TRANSPORTATION AND MARKETING

As with any industry, the raw materials of the petroleum industry must be transported to manufacturing centers and the finished products distributed to the consumer. At any point in this collection and distribution system the means must be provided to store greater or lesser quantities of the raw material--crude oil and gas--and of the products produced by refining. Thus storage, transportation and marketing operations round out the complex structure of the petroleum industry. Since these operations have many technical aspects in common, they can logically be grouped together for a discussion of related problems of environmental conservation.

Section 1.
BASIC OPERATIONS

The ramified storage, transportation and marketing system of the industry is illustrated by statistics which show that, in the United States alone, some 517,177 crude-producing wells feed 281 refineries which provide gasoline and oil to 219,000 service stations serving almost 90 million passenger automobiles and many other products to ancillary facilities. Untold miles of steel pipe are laid to bring oil from bearing rock up to the surface, through larger crude-oil collection lines to the refineries, and through product pipelines to the distribution center, where a short truck haul reaches the service station or airline terminal. At last, the oil brought up from any of half a million wells enters an automobile in the form of gasoline, lube oil, grease, transmission oil, etc.; or enters an aircraft as turbine fuel or other petroleum product; or is used in a truck, bus or other domestic or industrial consumer. In 1970, total U.S. demand for all petroleum products, including petrochemical feedstocks, reached 5.37 billion barrels, and this is expected to increase to at least 8.15 billion barrels by 1980.

A. Normal Operations

The arterial nature of the system which interconnects the many components of an integrated petroleum operation is very fortunate from a pollution standpoint. Within the continental United States, liquid petroleum sees very little other than the inside of a pipe during most of its journey from underground to the automobile or plane. The few exceptions are during refining itself, in storage, or in movement by tanker, barge, truck or railcar. Even the vast tonnages of petroleum moved by tanker on the world's oceans are within a closed system during the many miles of its storage and movement at sea. The point to be made here is that petroleum is handled almost exclusively in liquid form in what, except for points of transfer, is essentially a closed system from source to customer.

The same point may be made for natural gas. Here, again, the arterial nature of the natural gas pipeline distribution system across the land is fortunate from a pollution standpoint, as this useful gas sees nothing other than the inside of a pipe during its long journey from gas separation plant to ultimate consumer.

B. Abnormal Operations

Upsets occur in all human activities, and the petroleum industry is no exception. Wells develop line leaks; collection lines develop leaks due to stress cracks, corrosion, natural phenomena or human factors; tanks develop leaks due to corrosion or settling; and vessels, trucks or railcars become involved in accidents.

All equipment and systems are designed to hold the number of upsets to a minimum. Lines are carefully designed for the maximum working temperatures and pressures, with extra allowances for corrosion and upsets. Operating control systems are designed, where possible, to be fail-safe; e.g., upon failure of electric power, steam or instrument air, control valves throughout the instrumentation systems are designed to go either open or closed, depending on which will provide minimum upset and maximum safety for the operating unit. Such "designing-out" of problems extends all the way through to the automatic high-level shutoff at the gasoline pump.

Despite the utmost in design care, emergency systems are required to accommodate the unexpected. The elaborate systems described in Chapter Five as being used in a refinery are used on a smaller, simpler scale throughout the entire petroleum system. Specially designed, and frequently elaborate, systems are used to overcome the unique problems of large, oceangoing tankers.

Section 2.
WATER AND LAND POLLUTION CONTROL

A. Storage of Petroleum and Its Products

1. General Causes of Spillage

Petroleum and its liquid products are stored at virtually all points of the industry's arterial system, from initial production to marketing. The sources and causes of liquid spills are essentially the same wherever the storage tank may be located, that is, spillage during loading and unloading (tranfer operations), leakage from tanks and associated pumps and lines because of corrosion or other deterioration, and rupture because of accidents or similar causes. These general types of sources and causes of spills are dealt with in greater detail in the chapters describing the various segments of the industry's operations where storage is necessary, i.e., as a local adjunct to production, transportation, refining and marketing.

The various types of tanks used for liquid storage are described in Section 3 of this chapter because of the major design features related directly to prevention of the escape of vapors. Generally, spillage of liquids which may contaminate the adjacent land or water is controlled by channeling minor spills into collection areas from which they may be readily removed or by the construction of walls or dikes around storage areas to contain relatively large accidental spills. Walls or dikes may also be constructed around areas subject to flooding from rivers or other natural bodies of water so as to prevent the flood waters from carrying petroleum products or waste into adjacent areas.

Offshore storage, however, can pose some unique problems which require unique solutions.

2. Offshore Storage

In recent years, drilling technology has permitted the moving of drilling operations further from land in the conduct of offshore oil exploration and development. In areas currently being considered in the continental United States, it is generally advisable to deliver production by pipeline to shore. In early years of domestic offshore development, storage of oil at offshore locations and barging to onshore terminals was attempted. Interruptions in deliveries as a result of bad weather conditions, especially during winter months, have caused this system to become less favored than the pipelining system. There remain, however, a few fields where the isolated location and small quantity of production may dictate offshore storage for economic reasons. It is conceivable that as exploration and development proceed farther from shore, economics could dictate the use of offshore storage facilities of a type that are prevalent in foreign operations. Any vast offshore storage facility certainly is a potential pollution source; however, the farther the installation is located from shore, the less likelihood that any escaped oil will do serious damage to the environment, since most marine life is concentrated in coastal areas.

At present, requirements for U.S. offshore production seem to dictate pipelines for delivery of oil to markets in preference to storage and transport by barge or tanker. Nevertheless, in anticipation that future conditions, as development proceeds farther from shore, will make offshore storage practical, a discussion is presented of storage means that are currently in the development process or the planning stage.

It is imperative that the petroleum industry find a more economical means of temporarily storing crude production while awaiting marine transportation to world refineries. At the present time, offshore storage facilities are being installed and operated in water depths up to 200 feet. It is expected that in the near future offshore storage and crude oil transfer facilities will be required in much deeper waters.

The size requirement for an offshore storage unit will depend upon both the lease production rate and the availability of marine transportation to unload the storage tanks periodically. A storage capacity equal to approximately 10 days of production has come to be accepted as a minimum standard.

Offshore storage varies in capacity from 10,000 barrels to approximately 1 million barrels, in water depths of 35 to 200 feet.

Offshore crude-oil storage facilities may be grouped into the six broad categories discussed below. Each classification describes the storage units in terms of the position of the primary tankage with respect to the surface of the water. They are--

- Elevated above-surface storage
- Floating storage
- Semisubmerged storage
- Submerged storage--moored
- Submerged storage--bottom-supported
- Combination storage--submerged and elevated.

a) Elevated or Above-Surface Storage

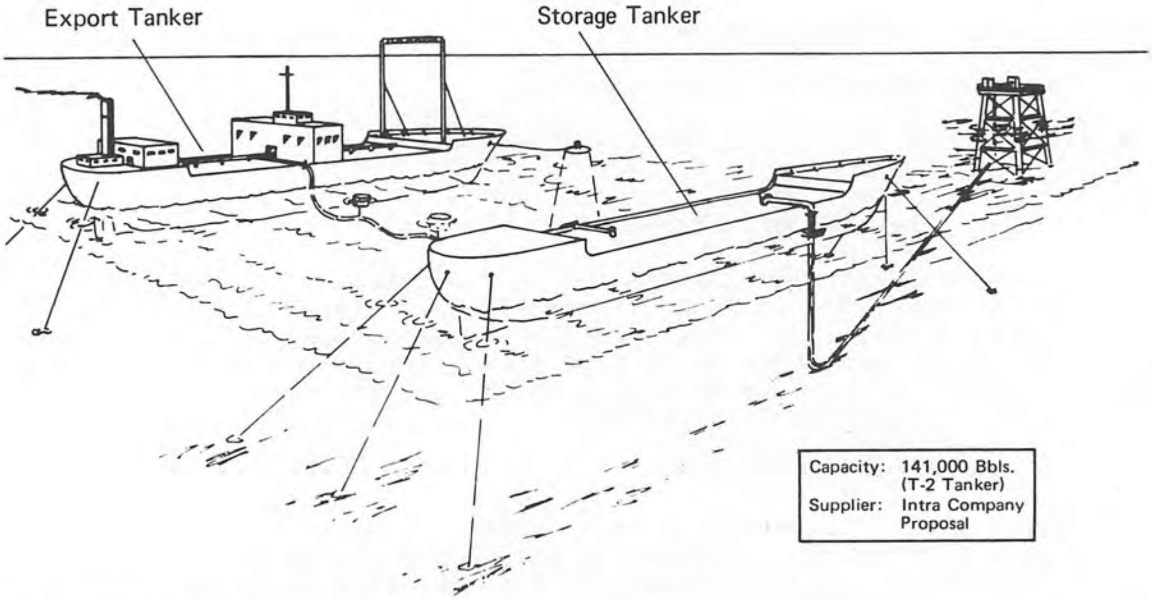
This type of storage facility is located on a platform above the surface of the water. Extensive use is made of special tanks placed on the decks of offshore production platforms. This type of storage frequently shares a platform with gas-separating and other production facilities. Structural capabilities of platforms used in the Gulf of Mexico normally limit on-deck storage to 10,000 barrels. Figure 49 illustrates this type of structure.

b) Floating Storage

This category applies to vessels such as barges, tankers (ships), and those tanks having a high positive buoyancy. Barges are frequently used in shuttle service during the early development phase of an offshore field. One barge receives oil at a production platform, while others are in transit between the shore terminal and platform. A marine tanker has been used to receive and store oil directly from producing wells which was in turn off-loaded into another tanker for transport to distant ports. Specifically built storage barges capable of holding 880,000 barrels of oil and having auxiliary oil treating and pumping facilities on board are also being used. Figure 50 illustrates this type of storage.

Photo: Courtesy of Sinclair Oil Corp.

Figure 49. Modern Offshore Oil-Drilling Platform (Alaska's Cook Inlet).



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 50. Floating Storage--Moored Storage Tanker.

c) Semisubmerged Storage

This type of storage applies to tanks moored in place which have a low positive buoyancy and float with only a very small fraction of their volume above the surface. The semisubmersible drilling platform-type structure lends itself to this use. Generally, this category of storage has been used in protected waters. (See Figure 51 for a specific example of this type of structure.)

d) Submerged Storage--Moored

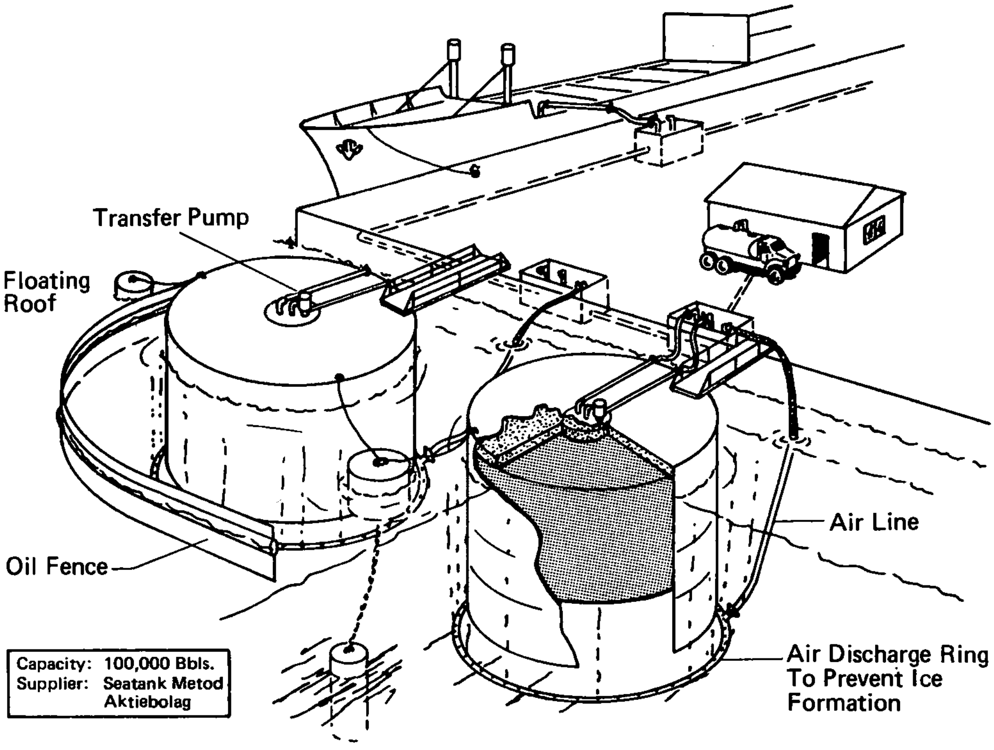
Submerged storage units may be either fully enclosed or bottomless. They have a low positive buoyancy and are normally moored at some point below wave action. They may be at or near the bottom (see Figure 52).

e) Submerged Storage--Bottom-Supported

This type of tank has a negative buoyancy and rests on the bottom without the aid of mooring lines. It may be either fully enclosed or bottomless. It may be attached to the bottom with piling to increase its resistance to drag by the current.

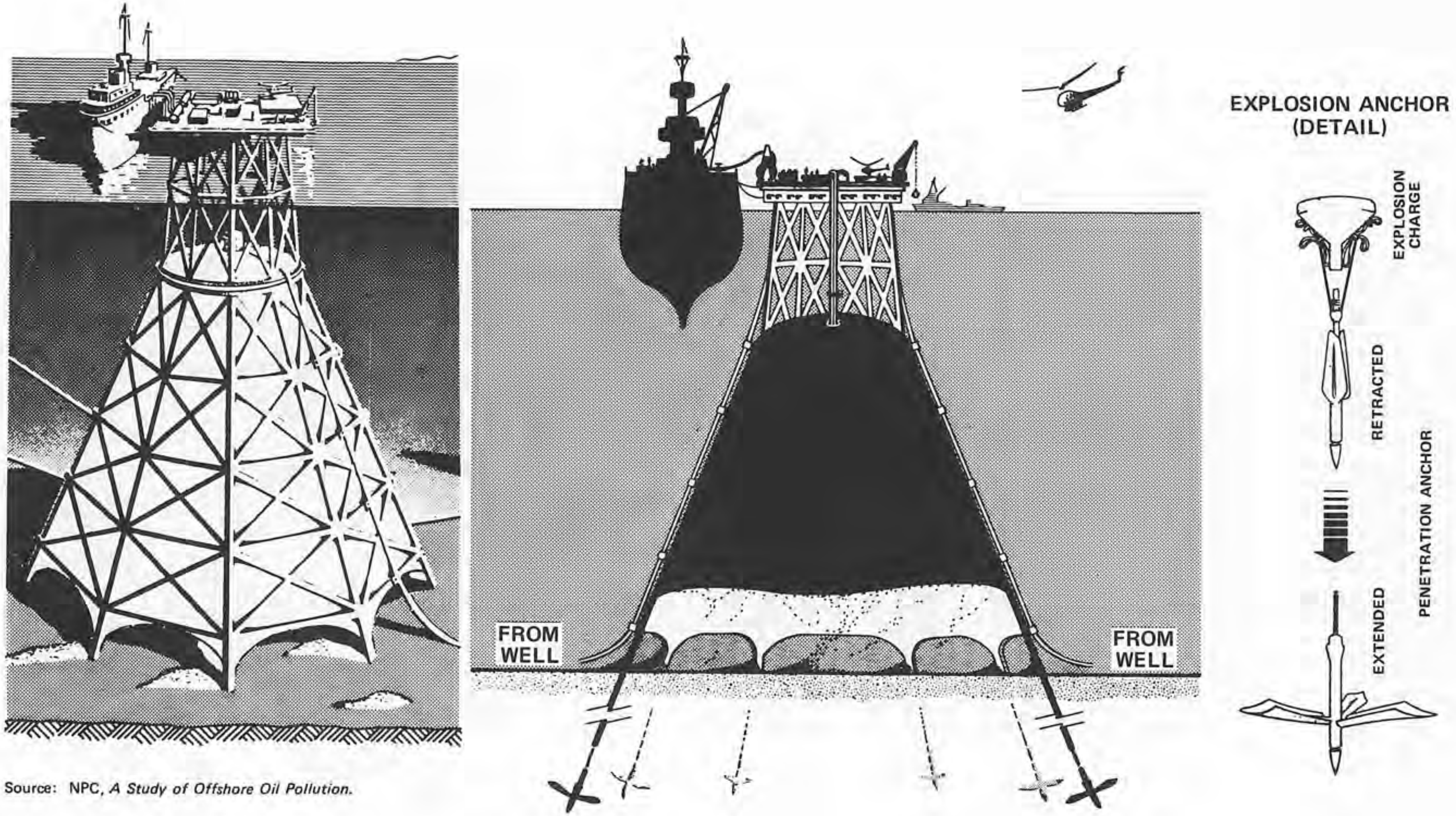
The storage tank is frequently equipped with an above-water structure which supports production, loading and submerged tankage control facilities. The above-water structure offers minor exposure to storm and collision (see Figure 53).

An example of sea-floor storage is the 500,000-barrel bottomless conical tank named "Khazzan Dubai I" and installed by the Dubai Petroleum Company in the Persian Gulf off the sheikdom of Dubai. It is permanently anchored to the bottom with piles. It converges upward to a relatively small neck projecting



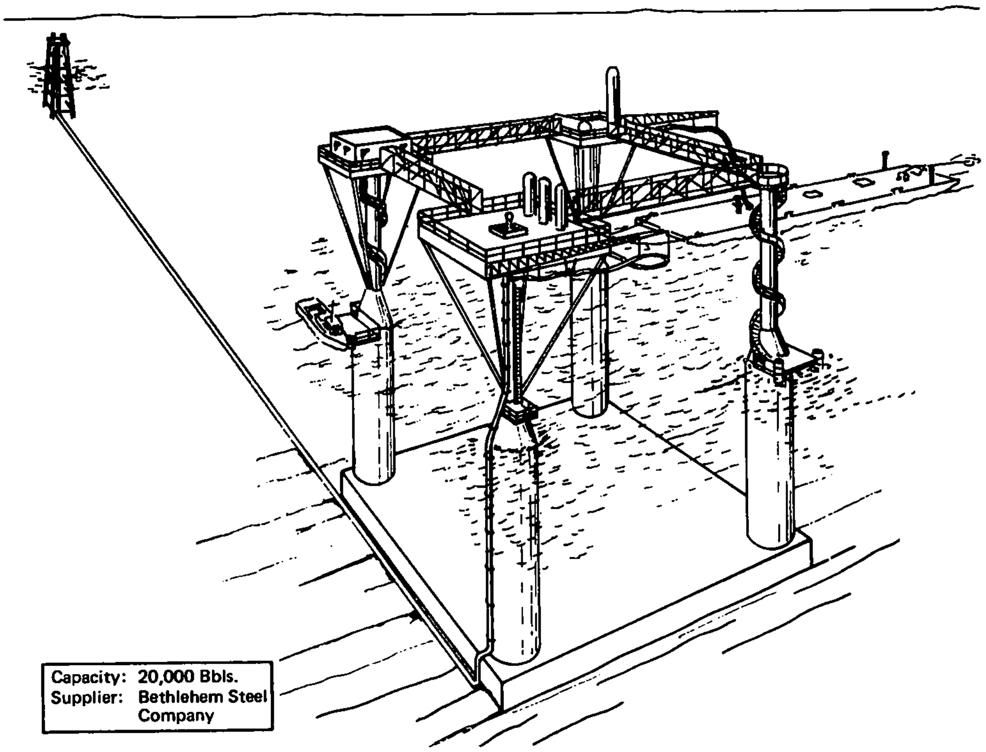
Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 51. Semisubmerged Storage.



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 52. Submerged Storage--Moored.



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 53. Submerged Storage--Bottom Supported.

above the water, carrying the switching and control equipment. The bottom for the oil storage tank is in the sea water. Figure 54 illustrates this type of storage.

f) Combination Storage--Submerged and Elevated

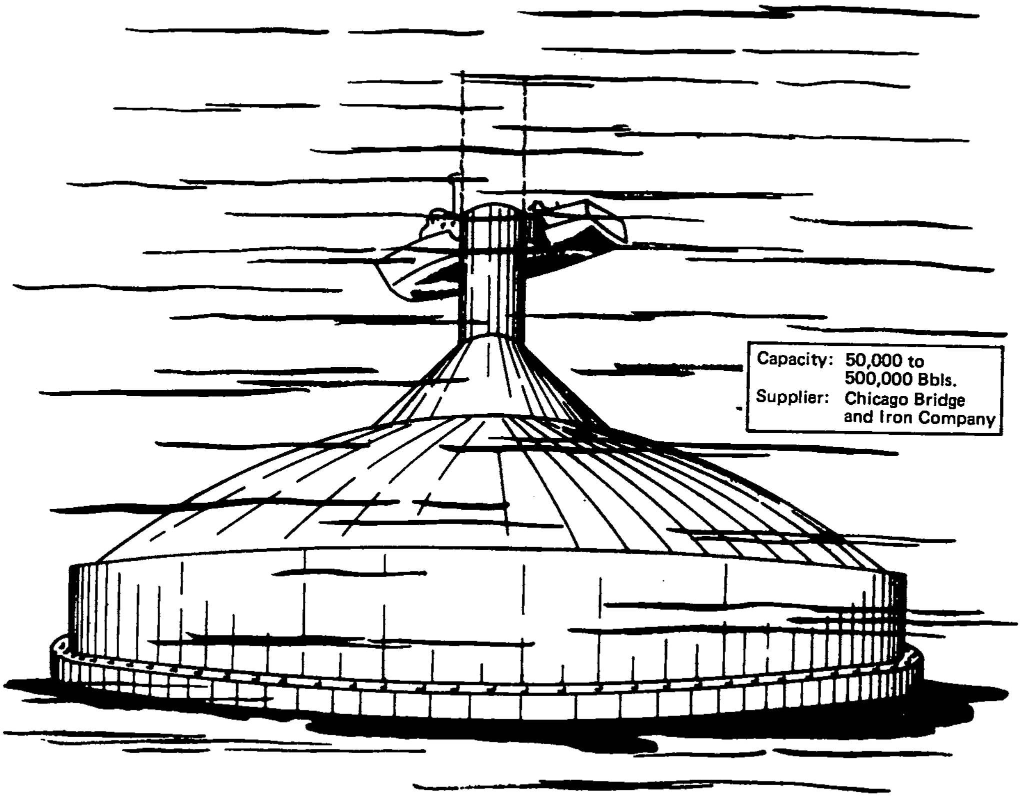
The principal storage unit in this type of facility is the submerged tank. The elevated tank normally has from 10 to 30 percent of the submerged capacity, and its primary purpose is to replace the subsurface ballast required in the conventional submerged facility to achieve an overall negative buoyancy (see Figure 55).

The submerged storage facility is most applicable in deep waters, is competitive with subsea pipelines when offshore production is at long distances from shore, and its large capacities are an advantage when the oil production is destined for distant refineries via supertankers.

3. Offshore Pollution Sources and Prevention

Major loss of stored oil or damage to the storage facility is possible from hurricanes, collision by seagoing vessels, blowouts on adjacent wells and fire. Failure of the facility may also result from undermining of the structure foundation by wave motion.

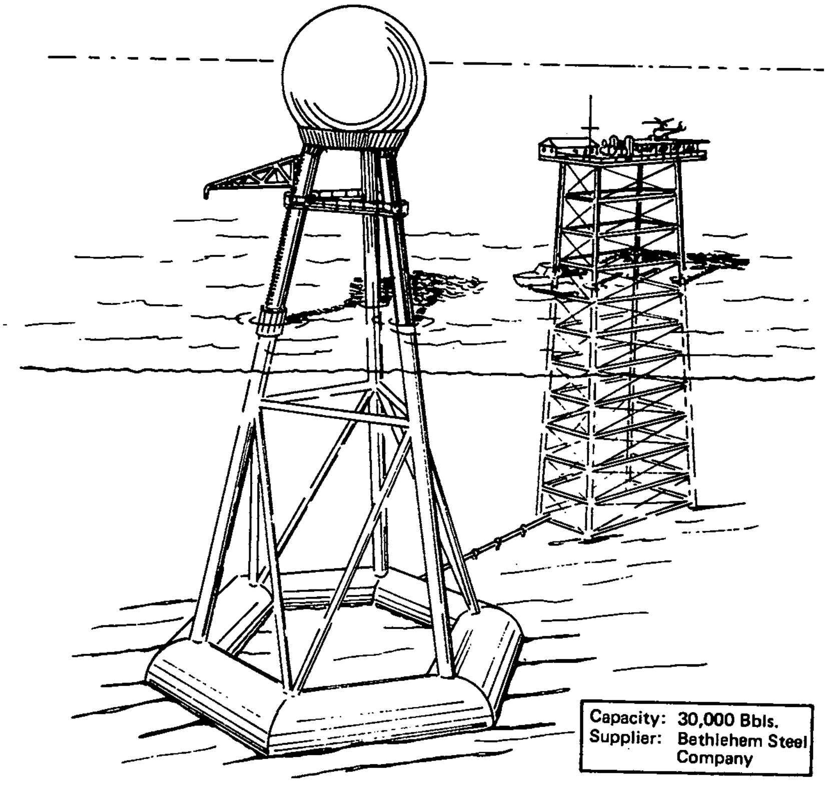
Experience has shown that almost any fluid spilled on a platform is a potential source of pollution. For this reason, it has been considered advisable that all decks be equipped with gutters and drains to direct the spills to a central gathering tank where the spill material may be treated or, if it is not suitable for treating, directed to shore for disposition without danger of pollution. Since a substantial part of spilled material contains flammable hydrocarbon material, it is advisable that adequate safety measures for prevention of fire and explosion be incorporated in the collection tank at the



Capacity: 50,000 to 500,000 Bbls.
Supplier: Chicago Bridge and Iron Company

Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 54. Submerged Storage--Bottom Supported.



Capacity: 30,000 Bbls.
Supplier: Bethlehem Steel Company

Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 55. Combination Submerged and Elevated Storage.

time of design and installation. Entrained gas, which is likely to be associated with any live oil spills that might be directed to the collection tank, should be provided for by connection of the collection tank to the offshore structure's gas-flare or vent-line system.

Fire control measures employed on offshore platforms are closely supervised by appropriate regulatory agencies. The systems may include carbon dioxide units, fire hoses, automatic sprinkler systems, dry powder systems and fog nozzle systems. Two or more of these fire-fighting systems may be installed on a single platform as dictated by individual needs.

Automatic operation of the fire control system is customary. If a fire is to be controlled by installed equipment, it must be controlled within a very few minutes of ignition. The carbon dioxide system is best for engines, generators, etc., and the water-spray and dry-powder systems are more often used for areas containing wells, manifolds, pressure vessels, etc.

Offshore structures in different parts of the United States may require considerably different designs to conform with environmental conditions encountered. In recognition of this, the various regulatory agencies have adopted rules suited to the area for which they are responsible.

Consideration must be given for the security of offshore storage facilities against water action, wind action and collision. In all offshore structures, the basic engineering considerations are: (1) rational design for the forces to be encountered and the loads to be borne, (2) realistic appraisal and forecast of the forces to be suffered, and (3) engineering study of the site on which the structure is to be built.

Maritime regulations and strengthened coordination between petroleum and other maritime activities will minimize the likelihood of collision of vessels with offshore storage facilities.

The key to prevention of fire and pollution is highly instrumented facilities, inhibition of corrosion, frequent inspection, early detection of leak sources, warning systems for major storms and ocean shipping, and highly trained, responsible operating personnel.

B. Transportation of Liquids by Pipeline

1. On Land

Admittedly, spillage of crude oil and liquid petroleum products can occur at any point along the many miles of pipeline used by the industry, whether they be flow lines carrying crude from producing wells to field storage tanks, field gathering lines, major trunk lines moving crude and products to refineries or terminals, or pipelines carrying products to consumer centers. The remarkable fact, however, is that an extremely small amount is spilled from this vast and complicated system. For example, analysis of 1968 data indicates that, of 6.5 billion barrels of liquid petroleum commodities transported by major pipelines, only six thousandths of one percent was spilled and much of this was recovered.*

a) Sources and Causes of Spillage

Pipeline accident reports are submitted to the Department of Transportation (DOT) on fatalities, injuries, losses over $1,000, and spills of over 50 barrels of liquid petroleum or 5 barrels per day of LPG. According to the

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* DOT Regulations 49 CFR 195 pertaining to liquid petroleum pipeline safety are reasonable and practicable, and the industry is complying with them.

Department of Transportation 1970 report, *Summary of Liquid Pipeline Accidents,* 90 percent of all accidents in pipeline systems in 1970 which could involve spillage occurred in the line pipe itself. Of the total accidents, 62.2 percent involved crude-oil pipeline; 18.2 percent, gasoline; 6.9 percent, LPG; 4.3 percent, fuel oil; and 2.9 percent, diesel fuel. Station and terminal piping accounted for 9 percent of total pipeline accidents.

The DOT notes in its *Summary of Liquid Pipeline Accidents* that 42.8 percent of all 1970 accidents were caused by external corrosion, thus showing this to be the major cause, by far, of pipeline accidents. Errors by operating personnel caused only 3.8 percent of the accidents tabulated, but this cause deserves continuing attention. Mistakes were made in calculating tank storage volumes, batch change arrivals and the timing of valve operations. Pipelines are now electric welded, as opposed to using material such as gasketed joints and acetylene welds that will fail with the passage of time and require continuing attention.

The Department of Transportation also reports that outside sources, primarily earth-moving equipment, accounted for 20.2 percent of all liquid pipeline accidents in 1970. Natural catastrophes such as landslides, earthquakes and floods were of minor magnitude in their effects on pipelines.

b) Prevention of Accidents

Code requirements were developed within the industry to ensure safety and stability of liquid pipelines. Many pipeline companies (purchasers of line pipe) retain outside testing laboratories to check the quality of pipe during its manufacture by the pipe mill. Samples of pipe metal are physically and chemically analyzed. Finished pipe is subjected to hydrostatic pressure tests, to fluoroscopic and ultrasonic examinations of longitudinal welds, and to radiographic examination of girth welds. During and after construction of the line, the pipe is generally subjected to hydrostatic pressure tests with pressures that exceed maximum operating pressure by at least 25 percent.

Protective coatings are applied to line pipe during construction. During operation the line pipe and pump station equipment are further shielded against external corrosion by cathodic protection. Internal corrosion is combated by chemical inhibitors or by dehydrating the hydrocarbons before they enter the pipeline. If repairs are necessary, present practice is to cut out a cylinder and weld in a new cylinder or cover the pitted area with a welded sleeve. At the same time, pipe in the area of the repair is cleaned and externally coated to provide protection from corrosion before backfilling.

Factors that may affect the life of uncoated pipe and thus affect the frequency of repairs are: adequacy of cathodic protection, inconsistency (excessive voids) in the soil adjacent to the pipe due to improper backfilling; foreign material and debris in the backfill, the proximity to extraneous electric currents and the conductivity of the soil. These are some of the factors considered when specifying the coating for a pipeline and when designing the cathodic protection for that line.

Properly applied coating has a very long service life and is extensively used today to prevent corrosion in areas where external corrosion is a problem. Electric holiday detectors are used during coating application to assure coating continuity. Before the pipeline is lowered into the ground, any gaps or weaknesses in the coating are patched. When repair records indicate corrosion problems have occurred on existing bare pipe, coating and cathodic protection are provided as necessary. Lines are replaced where repairs are not economical.

Earth, sand or cement bags are commonly used to cover and protect the pipe from external damage, and terraces and breakers are constructed to control the flow of surface run-off water. Erosion along the pipe right-of-way is prevented by planting grasses or, in special instances, by sodding over a completed site with new turf. Both practices improve the aesthetic appearance of the landscape as well as protect the pipeline. In Alaska, where pipelines are proposed, construction areas will be reseeded with native grasses to help restore the soil to its original condition.[261]

Periodic inspection and initial testing of the line also act to prevent accidents, as well as to provide greater assurance of appropriate control, should an accident occur. Lines are spot-checked periodically for corrosion along line excavations. When corrosion is suspected, surveys of pipe thickness are made with electronic instruments that travel with the internal liquid.

Aerial patrol of pipelines is a required practice to provide early warning of any abnormal activity along the line. Line markers and signs at road and large water crossings warn the public of high pressures and against excavating. Water crossings of pipelines are inspected regularly, and major lines are inspected by professional divers retained by the pipeline company.

Pressure control devices installed on pipelines are periodically tested to ensure proper operation. Line block valves are operated at regular intervals to see if they function properly.

c) Control and Removal of Spills

Pipe in inaccessible areas or over major water crossings is bracketed by line block valves so that flow can be blocked in emergencies. Line pressure sensors are utilized at pumping stations to automatically shut down pumps, close valves, and sound or flash alarms in the event of an accident, so that continuing application of pressure on a leak will be prevented.

Portable radio communication helps alert maintenance to remote line breaks or leaks. Pipeline managers ensure adequate coverage for emergencies by stationing crews and equipment at strategic locations along the system and by maintaining continuing contracts with pipeline construction specialists to make crews available on short notice.

At pumping stations sumps are used. At tank farms, when necessary, dikes are constructed around tanks, and skimmer lakes are used for protection of ground water and are built in the lowest elevations of drainage areas. The dikes contain oil lost because of tank overflow or rupture, and the skimmer lakes retain even the smallest seepage that may occur, thus keeping the ground or run-off water from being polluted. As a further aid to controlling oil runoff from a leak or spill, up-to-date topographic maps are made and retained to determine the course of any flow.

Spilled oil, which has been collected in pits formed by earthen dams, is then pumped into tanker trucks for removal. However, if an oil spill cannot be recovered before it soaks into the soil, several methods exist for cleaning the contaminated soil. Where permissible, burning is effective. Oil can be washed out of soil by flooding it with water, or soft detergents can be used effectively in certain soils. Evaporation and aeration are assisted by plowing or stirring the soil. The most promising new method is bacterial seeding, utilizing the Celludomanas species of bacteria plus certain fertilizers to decompose contaminating oil at a much faster than natural rate. Field tests of this method are still in process.[262]

2. Offshore

Today the use of long and large submarine pipelines at considerable depths is common practice, and new techniques had to be developed to accomplish this.

a) Systems and Procedures

Methods for joining lengths of pipe are many, but welding is the most popular and the least likely to develop leaks. However, other means have been used, including threaded couplings, flanges and numerous special couplings.

Basically, there is only one way to fabricate a pipeline--weld it together joint by joint. This simple technique is the heart of the lay barge operation. The pipeline is fabricated by adding one joint of pipe at a time and moving the barge forward in even steps to pass the joint through a series of welding and inspection stations along the assemblyway until the joining process is complete. Further forward movement of the barge passes the joint through the radiographic joint coating and other possible stations along the launchway as required to complete its integration into the pipeline. Precoating of the pipe for corrosion protection is normal, and if weight coating for negative bouyancy is necessary, this is done well in advance of the laying process.

Offshore pipelines are of several sizes, depending on their use, throughput and purpose.

A study of oil-industry demands indicates that flow and control lines between producing wells and gathering lines will require pipe size from 2 to 8 inches nominal outside diameter (OD) and are generally of relatively short length.

Gathering lines, which move the oil to central heating and pumping stations, are typically 6 to 12 inches OD with a projected maximum length of 50 miles.

Pipelines, generally in 20- to 48-inch OD size, are in wide usage. Lengths in excess of 50 miles are relatively common, with a few 100-mile subsea pipelines in service. A survey of industry needs indicated that 250- to 350-mile subsea pipelines will be required.

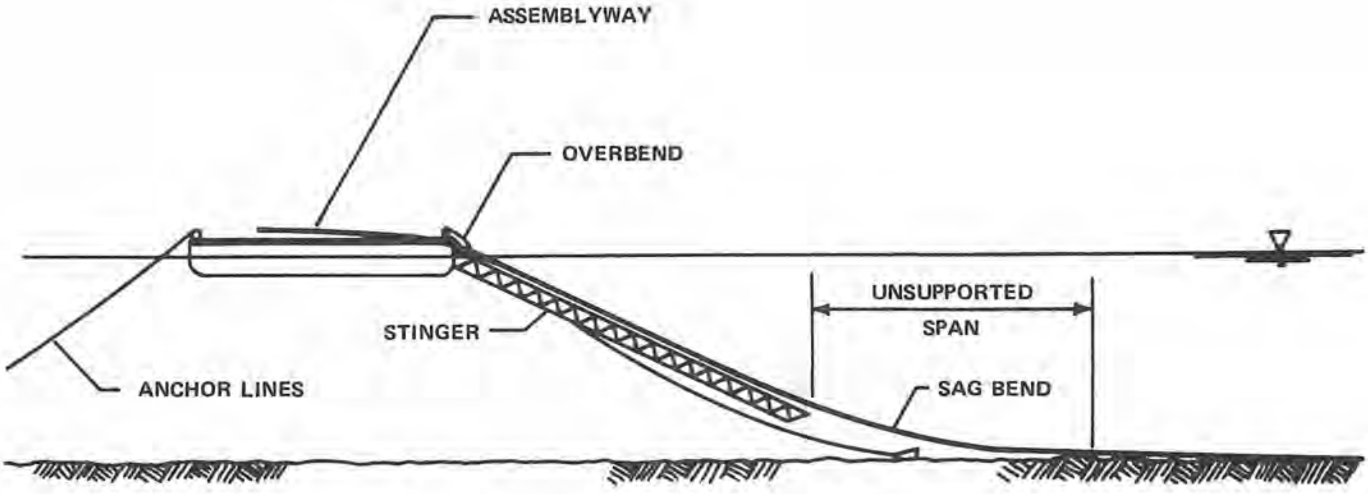
Pipeline capacities of 250,000 to 500,000 barrels per day are currently in use. Projected throughputs as high as 2 million barrels per day are planned for the larger (48-inch OD) lines.

Pipelines are usually laid under the sea bottom in trenches to protect them from currents and other external damage forces. Specially-equipped barges are used to lay the line. The line must be leakproof against both internal and external pressures. The structural strength must be sufficient to resist wave and current forces, and the pipeline itself must be able to withstand stresses during laying and stresses due to irregularity of the particular sea bottom.

Although there is virtually no danger of pollution as pipe is being installed, care must be taken to prevent faulty construction practices which result in damage to the pipe itself. Experience indicates that girth weld failure is not a significant problem, and those failures which have occurred are in those welds made by earlier techniques. Pollution because of failures can result after the pipe has been put in service. Perhaps the most critical phase of the construction process is the handling of pipe to avoid stresses beyond its minimum yield strength.

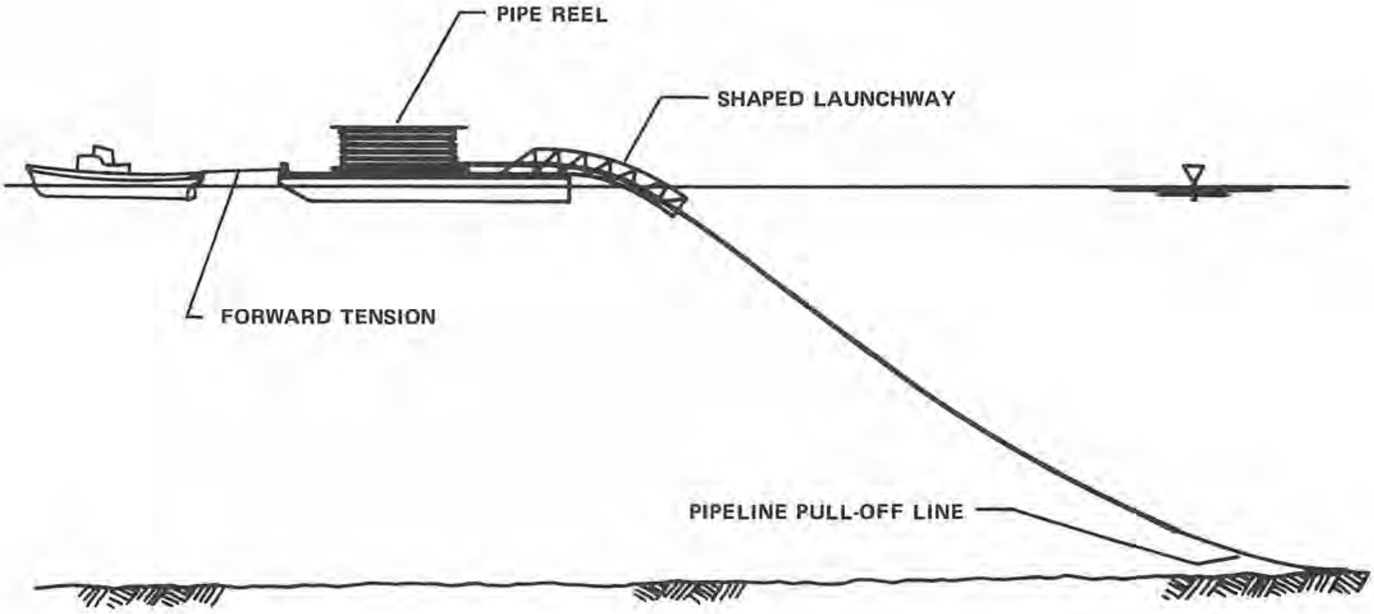
Two basic construction systems are in use today. The most common involves a structure, commonly called a stinger, which supports the pipe throughout its length from the laying barge or platform to the ocean bottom (see Figure 56). With proper care, this avoids any imposition of undue stress on the pipe. Because of difficulties in handling these sometimes enormous stingers, which are used to convey the pipe to the ocean bottom, there is a limit to water depth in which this system may be applied. A second system (Figure 57) is used which is less subject to the depth limitation. The pipe, when held in tension between the barge and the ocean bottom, will form a catenary curve which, in effect, converts it from a structural member to a cable member. As long as the tension is maintained as laying proceeds, the pipe is smoothly laid along the ocean bottom on the desired course.

When long lines are welded together joint by joint, the problem of maintaining tension is complicated by adverse weather and unanticipated shutdowns of the operation. To overcome this problem, a pipe reel system is in use for small-



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 56. Conventional Lay Barge Method with Straight Stinger and No Tension.



Source: NPC, *A Study of Offshore Oil Pollution.*

Figure 57. Reel Barge Method Using Tension to Keep Pipe Stress Acceptable.

diameter pipe in which pipe joints are welded together onshore and several miles of line are pulled onto a reel mounted on a barge. The barge can then be moved into location for pipe laying, which can be accomplished in a few hours. Scheduling for ideal weather must be arranged for this operation.

The most stable working platform of all is the land, and it is put to use as a pipe fabrication base when suitable. More frequently, a seagoing platform is required and a vessel is employed for the purpose.

Conventional flat-bottomed barges are in common use. They are relatively low in cost.

Ships are sometimes converted to pipe-laying vessels, usually as a matter of expediency in providing an inexpensive hull. The shipform vessel has a definite mobilization cost advantage because it tows well. Barges or ships are selected depending upon anticipated sea state.

The launchway serves to transfer the fabricated pipe string from the assemblyway into the sea. It is an integral part of the working platform, although it may be designed to assume different angles or configurations. It may be a straight extension of a high-angled assemblyway, or it may be a curving transfer system carrying the pipe from a shallow angle on the assemblyway to a steep angle at the launching point.

One of the major problems encountered in laying underwater pipelines concerns the means of supporting the pipe span from the point at which the pipe can safely sag to bottom. As mentioned earlier, a stinger is used except in very shallow water, to avoid excessive bending and possible buckling of a pipe.

The stinger is unique to the lay barge. It is a detachable extension of the launchway, intended to support the pipeline during its descent from the barge to the sea floor. It may be a truss framework firmly attached to the barge or a bouyant pipe ladder hinged to the barge. It may be straight, or shaped for some purpose, usually to hold the overbend in the pipe within an allowable stress limit.

By applying appropriate tension to the pipe, the stinger may be shortened, or even eliminated if the launching angle can be adjusted. During the welding operation on a lay barge, the pipe is gripped firmly so that tension may be applied through the barge positioning system. When the barge moves forward to launch a joint of pipe, however, the pipeline must be fed out in continuous tension, and the tensioner comes into play. The tensioner maintains a fixed amount of holdback on the running pipe until the barge reaches its new position, where the positive stop is reset.

Pipe can be spooled into a radius of curvature in the yield range of the steel and then can be straightened through the yield point when unspooled, with no appreciable change in dimensional characteristics. Large-diameter reels are used to spool pipe for this purpose and offer a convenient way to carry great lengths of prefabricated pipelines in a small area (see Figure 57). Sizes larger than 12-inch OD have not been adapted to this method. Six-inch OD and smaller are the most common sizes of pipe using this lay method. Weight coating with concrete cannot be utilized by this method, but heavier wall pipe can normally provide the necessary weight for negative bouyancy.

A simple method to reduce the stress in a pipe string extending unsupported between the barge and the sea floor is to attach pontoons, which will relieve the submerged weight of the pipeline. Pontoons may also be used to reduce the submerged weight of a pipeline being pulled along the sea floor, and consequently, to reduce the pulling force.

b) Pollution Sources and Prevention

The principal causes of oil leakage in pipeline systems are external corrosion, rupture or mechanical failure caused by outside forces. Pipeline terminals located offshore are subjected to the same hazards as are offshore production and storage facilities, and therefore must be protected against the possibility of storm or ship collision. While it is possible that pipeline rupture can be caused by excessive pressure or vibration of the pipeline in unsupported sections, the most likely cause is due to mechanical damage caused by anchors dragging across these lines.

Prevention of pipeline leakage is best attained by strict inspection procedures during laying operations and subsequent testing of the line prior to placing it in service. The pipeline may be inspected after it is installed on the sea floor if it is not buried. This is accomplished by divers, remotely controlled subsea television cameras, or from small submarines. Mechanical protection for the line can be provided by burying the line in the sea bottom and by utilizing high-strength weighting material not only to stabilize the line but also to provide protection against mechanical damage. Where the subsea pipeline is subjected to strong currents, the line may be stabilized on bottom by securing the line to bottom with explosive anchoring devices, or by using rock rubble or sandbags filled with cement to hold the line against the motion of the sea. Cathodic protection is sometimes used to extend the life of the pipeline and to eliminate the possibility of corrosive failure of the pipeline system.

C. Transportation of Liquids by Tankers and Barges

Oil on the ocean and coastal waters remains a major problem--one that is international in scope and encompasses operation of all classes of ships, as well as other operations, many of which are outside the U.S. petroleum industry's control. While tankers present the potential for large-scale spills, studies indicate that non-tankers in their daily operations are actually contributing to sea pollution to a greater extent than tankers through routine operational discharges which are frequently within the law.

Individual tanker mishaps can and have resulted in dramatically large oil spills. However, it should be noted that most of the aggregate amount of oil spills involves individual losses of small size. The latter occur primarily as a result of transfer operations and other routine operations of all types of ships.

In one sense, the United States is relatively more likely than many countries to be exposed to pollution by oil because of the great length of its coastline (12,383 miles), although traffic density in any particular location is also a factor. In addition to these extensive coastal waters, there are some 25,000 miles of navigable inland waterways in the United States.

Another factor is the great and growing requirement for petroleum products. The carriage of oil by water has doubled in the past 10 years, and this tremendous growth has multiplied the pollution problem in spite of preventive progress that has been made.

On the other hand, the practices of the U.S. petroleum industry are an offsetting factor. For many years the petroleum industry has taken positive steps to increase safety and minimize accidents in order to avoid oil spills. However, although significant progress has been achieved, even more advanced and more widely used standards and practices are needed for the prevention and control of oil spills occurring as a result of petroleum marine transportation and transfer operations--whether upon the high seas or upon U.S. coastal and inland waters.

1. Sources and Causes of Spillage

At present the United States is approaching a frequency of 10,000 oil-spill incidents a year.[263] These spills vary in size and consequence and are attributable to any one of a number of sources.

a) Sources

1) All Vessels

Although oil tankers are potentially the greatest source of oil pollution from vessels, we are not immune from the threat of oil pollution to a lesser degree from other types of vessels. The United States is subject to pollution of some kind from more than 5 million craft, classified as follows:

Vessels over 1,000 Gross Tons--International

13,832	Naval Vessels/All Types*
10,974	Dry Cargo Freighters
3,967	Tankers
2,676	Bulk Carriers
832	Refrigerated Vessels
966	Passenger/Freighter Combinations
33,247	Total

Vessels 1,000 Gross Tons or Under--U.S. Registry

42,242

Pleasure Craft--Non-Certificated

5,000,000 Plus

Each of these vessels poses, to a varying degree, a pollution threat to the coastal waters, harbors, rivers, lakes, bays and sounds of the United States. These vessels include not only those embarked on inland or intercoastal trips, but also these which may call at U.S. ports in the process of carrying international commerce or for other purposes. Consequently, consideration must be given to pollution by all vessels that ply U.S. waters, regardless of nationality.

2) Tankers

It has been forecast that world tanker requirements in the next 10 years will average one hundred 200,000-DWT ships per year for a total of 1,000 ships.[264] U.S. requirements for sizes of individual tankers have been forecast to be--

- East and Gulf Coast of the United States: up to 70,000 DWT
- West Coast of the United States: up to 250,000 DWT.

Much larger ships would be used to supply U.S. East Coast requirements if presently limiting factors--harbor depths and terminal restrictions on the East Coast--were to be overcome. At this time a proposal is pending for a large oil terminal on an island in the harbor of Portland, Maine. A combination of environmental and economic factors will govern vessel size for supplying the East Coast.

The list on the following page indicates U.S. companies that have in service or on order tankers of approximately 70,000 DWT or over. Although U.S. tankers are smaller than newly built foreign tankers, the universal trend is toward large tankers. The average age of U.S.-flag tankers is 16 years, 10 months. Therefore, new building programs are expected to flourish in the near future in order to meet an estimated requirement of 4 million DWT between now and 1980.

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*This total includes vessels in reserve. United States includes Coast Guard vessels. U.S.S.R. figures estimated in round numbers. Source: F. T. Jane, *Jane's Fighting Ships, 1968/69* (New York, Arco Publishing Co., Inc., 1969).

Presently in Service	DWT
ESSO SAN FRANCISCO	75,600
ESSO BATON ROUGE	75,600
ESSO PHILADELPHIA	75,600
ESSO HOUSTON	71,500
ESSO NEW ORLEANS	71,500
JOSEPH D. POTTS	80,700
SOHIO INTREPID	80,700
MANHATTAN	115,000
AMERICA SUN	80,000

On Order	DWT
Socal	3- 69,800 EA
Atlantic Richfield	2- 69,800 EA 3-120,000 EA
Maritime Overseas	1-120,000
Steuart Transp.	3- 78,000 EA
Union Oil	1- 69,800
Seatrain	2-230,000 EA

b) Causes

Oil pollution from vessels can occur (1) through improper operations, including pumping of oily bilges and disposal of oily tank washings or ballast from tankers, and (2) through those mishaps that result in the release of oil.

1) Improper Operation

Tank Washings and Dirty Ballast. First and foremost of the principal causes of oil pollution is the discharge of dirty ballast and tank washing by oceangoing tankers, most of which are engaged in international trade. Estimates of the magnitude of the problem range widely. One estimate is that 400,000 tons of oil per year are discharged into the open seas because of this.[265]

Bilge Disposal by All Craft. The second principal source of oil pollution by improper operation is the pumping of bilges overboard from thousands of vessels, big and small. Oceangoing vessels generally refrain from such practice until well at sea; therefore, damage, if any, is difficult to assess. Passenger vessels and some types of dry cargo vessels find it necessary, as fuel oil is consumed, to replace it with water ballast in order to maintain proper stability. In some cases, this practice requires filling bunker tanks with seawater ballast, resulting in contaminated water which must be disposed of overboard unless facilities are available at the bunkering port to receive this dirty ballast. In many cases time and circumstance do not permit disposal of this ballast in port. In inland waters, tugs, barges, ferries and the multitude of diverse marine craft that ply our rivers, lakes, bays and sounds pump their bilges into our navigable waterways, with quite a noticeable effect on the marine environment. Of no small consequence is the practice of more than 5 million pleasure craft that traverse the Nation's waterways and use them as depositories for diverse wastes.

Disposal of Other Wastes. Even though oil pollution is a cause for concern, the discharge of raw sewage and food waste from the multitude of vessels that daily ply our waters is also significant. Very few vessels are fitted with equipment to handle raw sewage or the disposal of food waste, and very few marine terminals provide disposal facilities of any nature whatever.

Human Error and Malpractice. Oil spills attributable to human error occur in a number of ways but principally result from poor communications or carelessness. For example, a tank can overflow during loading due to crew negligence or failure of communication with the loading terminal. Spills can occur because a valve was left open or a blank was left off a manifold header.

Failure to properly maintain and operate equipment can cause mechanical and equipment failures leading to spills. These failures can take many forms, such as ruptured hoses and pipelines, broken valves, etc., but such failures can be minimized by regular programs of testing and preventive maintenance. It is encourageing to note that there is a decided upturn in the use of crew training programs designed to impart a sense of awareness and importance of proper operational procedures which will minimize environmental damage.

2) Mishaps

Collisions and Groundings. A prominent cause of oil pollution is collision and/or grounding of tankers or barges engaged in bulk transportation of oil. This type of pollution from vessels, because it often receives wide publicity, is the best known to the public. Of course, large spills of the type from the *Torrey Canyon* can be a major problem, but the cumulative amount of all pollution caused by collisions and groundings is somewhat less than pollution caused daily by all other sources.

Recent survey figures compiled by the American Institute of Merchant Shipping forecast that we may expect 12 collisions in the next 10 years of sufficient magnitude to dump between 77,000 and 110,000 cubic meters of oil in the water per year. These estimates are for global coverage and, in view of past experience, the chances of a *Torrey Canyon* disaster in U.S. waters are relatively small.

U.S. Coast Guard statistics indicate that human error is the greatest single contributing factor in collisions and/or groundings of vessels.

Operating Conditions. Spills at sea can result from a number of causes. Mechanical and equipment, as well as human, failures sometimes can result in collisions or groundings. Vessels of all types have suffered explosions of unexplained origins and have in some cases disappeared at sea or broken in half due to severe weather or improper loading.

Random pollution incidents are common to all vessels. Therefore, even though the loaded tanker poses the greatest potential quantity of pollution from oil, other types of ships contribute to pollution frequently and regularly.

2. Methods of Improvement

More detailed descriptions of methods of prevention and control of oil spills are given in the sections which follow. Generally speaking, however, research and development sponsored by the petroleum industry is continually directed toward prevention of occurrence of oil spills by improving equipment reliability and pollution-control techniques, even beyond the standards of national statutes or international law. From this industry effort have come "load-on-top" techniques for transport tankers, development of on-board oily-water separators, improved loading and unloading procedures, and the building of more and larger shore ballast-handling facilities in order to reduce even further discharges anywhere at sea.

The number of tankers lost in 1969 was reduced by about 25 percent from the average of such losses recorded in the previous 3 years. While this short-term trend is encouraging, the industry is seeking marked further improvement through several programs. Research projects are under way to improve navigation systems and to develop steering devices that will increase the maneuverability of ships so as to prevent collisions, although the basic problem is to maintain distance. Ship designers are investigating a variety of new features, including double-skin hulls, to minimize the seriousness of accidents. In addition, individual companies are increasingly emphasizing the training of ships' personnel, both at company schools and aboard ship, to improve navigation and general operating techniques.

Internationally, the industry has strongly supported the efforts of the United Nations Intergovernmental Maritime Consultative Organization (IMCO) in improving international standards of vessel design and operation to prevent pollution, and in developing international agreements prohibiting discharges of oil at sea (see Chapter Ten, Section 3). Even though international law allows some oil discharge 50 miles or more from shore, depending on locale, most oil companies are now attempting to achieve a practicable, strict policy against discharge of oil or oily ballast anywhere in the world's oceans.

While the industry is working hard on all aspects of prevention of oil spills, it also recognizes that with about 4,000 tankers and 30,000 other large ships plying the world's oceans, some accidents may still happen. The industry has therefore taken steps to be sure that means are available to handle the costs of cleanup of oil spills and to reimburse persons sustaining pollution damage. For example, a voluntary plan has been instituted for handling the costs of cleaning up oil discharges from tankers operating in any part of the world's oceans.

Barge movements on inland waterways as well as in coastal waters represent an important part of the Nation's petroleum traffic. Several types of technical, procedural and training projects applicable to tankers are also generally applicable to barges and their movements. The industry actively supports increased attention to harbor cooperatives, to cleanup of oil spills, and to broader arrangements with concerned local and federal groups for such purposes as providing waste-disposal facilities and minimizing the effects of oil spills in coastal and inland waterways.

The National Petroleum Council endorses governmental efforts to improve coordination and transportation support services so as to minimize mishaps and damage from oil spills. The emphasis of the Water Quality Improvement Act of 1970 on creation of an improved National Contingency Plan is a step forward. Improved weather forecasting, ship lanes and navigational aids would provide additional means of preventing spills. Better controls and international standards are needed in all forms of shipping. Likewise, advanced cleanup techniques would improve the means of controlling spills. The petroleum industry and its individual members have mounted a substantial effort and considerable research to improve ability for the prevention and control of oil spills. This effort is being closely coordinated with related governmental programs.

a) Attention to Pollution Control

Attention to control of pollution of water and land by oil spilled from use of vessels is a matter which concerns all of society--industry, government and the general public--for all use ships on the waters and all bear the societal costs. Furthermore, all have a direct or indirect responsibility for such relevant factors as human performance; the installation, operation and use of navigational aids; and the creation of and compliance with appropriate law and regulation. This interrelationship of responsibility is apparent from examination of attention that has been given and can be given to specific operations.

1) Control of Tank Washings and Oily Ballast

To combat oil pollution from disposal of oily tank washings or ballast, the industry instituted the "load-on-top" procedure some years ago. This procedure may be generally described as retaining on-board ship the oil-water mixtures resulting from tanker compartment cleaning or from use of compartments to carry ballast so that they will commingle with compatible new cargo loaded "on top." The voluntary practice of load-on-top has gained momentum in the past several years, with the result that oily waste dumped into the ocean has been reduced from an estimated 1,000,000 tons annually to 400,000 tons annually. The applicability of this system depends on the availability of disposal facilities at the port of destination.

A combination of the load-on-top method with use of on-board oily-water separators is the most advanced system in use today for the handling and disposal of tank washings and dirty ballast on long-haul voyages. For example, when a ship sails from the discharge terminal, it has on-board ballast water approximating 40 percent of its deadweight capacity. On the sea passage, after the oil and water have been separated, the uncontaminated water is released overboard by carefully monitored pumping (decanting) of each ballast tank. When the level of liquid in the ballast tank reaches the point where the surface crude-oil layer is reached, the tank is shut off. The remaining liquid is pumped into a settling tank provided for slop water and crude-oil mixtures. The ballast tank is then washed and the tank washings are pumped into the settling tank. The contents of the settling tank are then put through the oily water separators. The clean water from the separators is then discharged over the side and the water-free crude oil placed in yet another tank, to be added as part of the next cargo.

It is estimated that the load-on-top procedure is utilized by some 80 percent of the vessels in international tanker fleet. However, its effectiveness in the final analysis depends on the dedication of the tanker officers and crew to the need for minimizing ocean pollution. This again emphasizes the importance of sound training programs.

The equipment and procedures used aboard these new vessels to control oily washings are complemented by new terminal facilities that provide adequate ballast storage and an operational system which integrates the capabilities of the mammoth tankers with shuttle tankers. This "ballast storage system" calls for shuttle tankers, when docked at the new terminal, to pump dirty ballast directly into the mammoth tankers when their respective schedules coincide. When their schedules do not coincide, dirty ballast from shuttle tankers is pumped ashore and stored for use on the mammoth tankers when needed. By passing contaminated ballast from ship to ship, the problem of pollution attributable to dirty ballast is minimized.

With this system, no oily waste goes over the side, and significant quantities of crude oil are recovered during the ballast voyage. This system, however, is usable only at terminals at which tankers are loading while other tankers are discharging and where the tankers are properly fitted to receive and discharge ballast over the dock while simultaneously loading or discharging cargo. Waste-oil disposal facilities are only available at a limited number of ports.

2) Control of Bilge Liquids and Other Wastes

Engine room bilges on all types of vessels, large or small, almost always contain oil, and it has always been a universal practice to pump these bilges overboard. Likewise, sewage, human waste and food waste have always been discharged overboard. There are two possibilities for correcting this problem. The first is by treatment and the second is by establishment of receiving facilities onshore used in conjunction with holding tanks on vessels. Both of these methods are feasible, and in time, this problem can be solved.

3) Terminal Facilities

Examples have already been given of the use of terminal facilities in the control of pollution from ships, but the role of terminal facilities is more extensive and of sufficient importance to deserve separate discussion.

Waste Disposal Facilities. Appropriate facilities are generally lacking for disposal of a ship's wastes. The master of a ship cannot properly dispose of dirty ballast, tank washings, bilge waste or sewage without being provided with some specific place to put such wastes. (The vastness of the open seas has historically provided a ready-made and convenient depository.) With the lack of waste-disposal facilities onshore, in inland or coastal waters, the demands of the shipping trade often lead the shipmaster to resort to disposal of these wastes under cover of darkness in order to escape fines. However, where terminals provide facilities for disposal and enforce their use, the incidents of pollution from oil, sewage and other wastes are conspicuously few.

Most shipyards do not provide adequate tank-cleaning and slop-disposal facilities; many provide no facilities whatever. Other shipyards that do provide tank cleaning and slop disposal services sometimes dispose of the residue by dumping it at sea much closer to the coastline than the ship would have done in the first place.

A shipmaster must dispose of ship's wastes in order to maintain his vessel in a condition necessitated by the nature of the trade. Therefore, the greatest single step toward curbing the major cause of oil pollution would be to require sufficient facilities at terminals, shipyards and other marine facilities, to provide for disposal of both oil slop and collected residue (waxes, rust, etc.). This problem deserves attention by all users of the ocean for transportation.

Very Large Tankers. As indicated earlier (see Chapter Three), the motivation to reduce the unit cost of hauling has led to increased size in all forms of transportation--pipeline, truck, aircraft or tanker. Similarly, the terminal facilities of these modes of transportation are being continually changed to realize the advantages of the increased size of the carriers.

The great numerical advantage of the 300,000-DWT tanker is that it transports the equivalent of about 20 T-2 tankers, thus greatly reducing the unit cost, the quantity of traffic which must be handled and the number of voyages which might cause a polluting incident. The size and draft of these vessels have necessitated the building of port and terminal facilities to meet the new requirements instead of adding to the congestion of old facilities, many of which are already grossly obsolete. These new terminals are, in many instances, in relatively isolated locations well away from the mainstream of congested traffic lanes, thereby reducing the exposure to collision. In this regard, the past several years have seen a dramatic growth in world use of the single-point mooring buoy, designed especially for the loading or discharging of tankers in the open sea. These buoys are usually located well offshore, in some cases as far as 10 to 15 miles, depending on circumstances and water depth.

A complete revamping of the present petroleum terminal system generally utilized by the industry would minimize chances of pollution and better realize the advantages of modern transportation. A few selected locations designed specifically for the use of very large tankers would provide particular advantages in that--

- Obsolete oil berths in areas of high population concentration could be eliminated.
- The maneuvering of very large tankers in congested waters would be precluded by providing offshore loading berths or inland berths away from any other type of marine transportation.
- The new facilities could be designed in accordance with modern standards specifically to control pollution as well as to meet other requirements of the industry.

Europort, in Rotterdam, Holland, is an example of a workable port arrangement that could accommodate a petroleum industry complex which would not penalize industry and would adequately serve the best interests of the public.

4) Tanker Loading Procedures

Although oil pollution from an overflow of a cargo or bunker tank is often attributable to carelessness, inattention to prescribed procedures or human error, a number of innovations have been developed to reduce or eliminate such sources.

Many refineries are located on navigable waters and operate docks for receiving or shipping oil by tanker or barge. The procedures employed for loading and unloading ships and barges are governed largely by safety regulations which inherently include the prevention or minimization of oil spillage. While it is realized that transfer procedures may vary from location to location, depending upon the particular facilities or circumstances at the location, the basic practices are usually similar.

Long-standing procedures for prevention of oil spills and for vessel safety will generally include the following practices and/or facilities:

- Routine (at least yearly) hydrostatic testing of transfer hoses
- Equipping all vessel transfer pumps with check valves in the discharge line to prevent backflow through the pump while unloading and resultant possible overflow of tanks
- Proper plugging of scuppers aboard ships during transfer operations
- Trained personnel in attendance on both vessel and dock at all times while transfer operation is in progress
- Frequent inspection of the water in the immediate area of the vessel during transfer operation to detect possible overboard leaks
- Proper sequence of valve openings prior to transfer operation and valve closings upon completion of transfer operation to prevent excessive pressure on transfer hose
- Decrease in loading rate while topping off vessel tanks to minimize possibility of overflow
- Evacuation of transfer hose after completion of transfer and before removal of hose
- Use of drip pans or drip collection systems under all transfer hose connections, both on vessel and on dock
- Proper dock construction to prevent spills on dock from flowing into the harbor and to minimize possibility of line leakage into water
- Use of control systems enabling dock personnel to shut down remotely located loading pumps
- Prohibition of cargo loading until a vessel has completed discharging ballast if the ballast is being discharged through a sea suction. All sea suctions are sealed before loading cargo. Obviously, discharge of dirty ballast overboard is not permitted.

New mammoth tankers contain a central control room from which the operator can remotely control every cargo valve on the vessel, stop and start the pumps and, through remote instrumentation, observe the exact level of the cargo in each tank. The officer in charge is also equipped with VHF radio so as to be in constant communication both with the shore-side control tower at the loading or discharging terminal and with the men on deck. Because of the great length of the main deck, the ship's officers and crew are equipped with two-way, walkie-talkie radios so they are in constant contact with the central control room and each other.

This combination of a central control room with instant communication about the vessel and with the shore-side installation provides positive control of the loading of very large vessels.

5) Equipment and Maintenance

Marine equipment manufacturers continue to improve their products generally and have developed new aids of specific assistance to the petroleum industry in a number of areas, particularly in the field of electronics. Vessels now can be equipped with instruments that indicate loads and stresses. Closedcircuit television can be used to monitor machinery. Automatic or remote-control devices aid in all aspects of the vessel's operation.

Coatings to protect against corrosion have been greatly improved in the past several years, with a resulting added safeguard against structural failure and simplified cleaning of the ship. In spite of these precautions, oil pollution sometimes occurs from fractures in shell plating caused by heavy weather which can neither be avoided nor its effects controlled.

The responsible elements of the petroleum industry maintain engineering staffs, inspectors and professional shipboard personnel to carry out preventive maintenance aboard ship and to ensure that appropriate inspections and repair are accomplished in drydock. The U.S. Coast Guard enforces laws governing safety of U.S. shipping by examining and approving all lifesaving apparatus, by inspecting each U.S.-flag vessel biennially, and by conducting a special hull and machinery survey every 4 years. Hull and machinery underwriters, along with the various classification societies, are constantly seeking ways to improve equipment.

Although there are present regulations and procedures for the inspection of all vessels, the operating condition of vessels would be improved by the development and enforcement of international uniform standards applicable to all vessels, regardless of ownership or flag of registry. For example, international agreement as to the maximum time a vessel is allowed to remain in service between drydockings would improve maintenance worldwide. At present, a considerable economic disadvantage is imposed on ship owners who are bound by rigidly imposed regulations as opposed to owners not so bound.

Generally speaking, oil pollution from vessels is proportional to the condition of the ship's equipment and the quality of the ship's operating personnel. Accordingly, international establishment, through the Intergovermental Maritime Consultative Organization, of sound standards for equipment and uniform procedures will reduce the pollution threat to the United States and to other nations.

b) Collisions and Groundings

The great majority of collisions and groundings occur in confined waters. Poor visibility, traffic congestion and lack of communications are contributing factors.

1) A General Problem

The problem is not, of course, limited to oil tankers. All ships, large and small, commercial and noncommercial, private and government-owned, are faced with the problem. Neither is the problem solely an American problem. On the contrary, it is a matter of general international concern and responsibility. As a consequence, IMCO has, as a major responsibility, the function of providing a forum for international discussion and agreement on ways and means of preventing groundings and collisions. In an effort to overcome the problem, the Council of IMCO, at its Third Extraordinary Session held in London May 4 and 5, 1967, discussed specific measures to prevent groundings or collisions that might result in oil pollution and to mitigate damage from such pollution. The following 18 items, which were proposed for investigation and consideration, provide a comprehensive listing of the many factors which affect the problem and the spread of responsibilities over government, industry and the private citizen:

1. Establishment of special routes or lanes and the consideration of prohibited areas

2. Shipborne navigation aids

3. Guidance of ships from shore-based stations and Port Advisory Services

4. Restrictions of speed and maneuvering capabilities of the ship
5. Periodic testing of shipborne navigation equipment
6. International standards of training and qualifications of officers and crew
7. Use of the automatic pilot
8. Design, construction and equipment aspects
9. Charting of routes and adequacy of charts and publications
10. Reinforcement of lookout system
11. Regional or interregional contingency planning
12. Continuation and intensification of research
13. Possible additions to the International Convention for the Prevention of Pollution of the Sea by Oil, 1954, as amended
14. Affected state's ability to participate in any official inquiry
15. Measures that a state may take to protect its shoreline
16. Liability of owners or operator for damages to third party
17. Access of seaborne salvage equipment of other flags into territorial waters
18. Surveillance and control by coastal states.

2) Design, Construction and Equipment Aspects

One of the measures in which members of the oil industry, as owners and operators of large tankers, have a major interest is the design, construction and equipment of such large tankers. The objective is to avoid or lessen the escape of oil or other noxious products in the event of stranding or collision.

The purpose of discussing this subject at the 1967 IMCO meeting was to explore the idea that consideration be given to "the possibility that the International Convention for the Safety of Life at Sea should be amended to control the design, construction, and equipment of ships above a certain size carrying oil or other hazardous cargoes." As a consequence of this discussion, the marine industry has conducted an in-depth study on the need, effectiveness and practicality of additional construction and equipment requirements as a possible means of (1) reducing the risk of collision and grounding, and (2) avoiding or limiting pollution by oil and other types of liquid cargo in the event of collision or grounding.

The following 15 major areas of ship design were considered in this study:

1. Maneuvering ability
2. Course instability
3. Bow thruster
4. Astern horsepower
5. Braking devices
6. Stopping ability

7. Multiple propellers and rudders
8. Controllable pitch propellers
9. Auxiliary boilers
10. Remote control
11. Steering-gear power source direct from emergency generator
12. Tank arrangements--size and arrangements of tanks including isolation of tanks from side of hull
13. Double bottoms
14. Piping arrangements
15. Oil-salvage arrangements.

Ships breaking in half or suffering structural damage because of weather or improper loading or discharging of cargo has long been a problem to ship owners, builders and the classification societies. To overcome these problems, a number of selected very large vessels of all types have been fitted with built-in, continuous-monitoring stress recorders that measure the effect of wave action on the hull in addition to the effect of stress created by the distribution of cargo within the hull. The accumulated information received from the continuous monitoring of the stresses exerted upon the vessels will provide naval architects and the shipbuilding industry valuable information in the design and construction of vessels capable of withstanding greater stress.

3) Traffic and Vessel Control

Progress is being made in several of the areas discussed at the IMCO Council sessions concerning traffic and vessel control.

All Vessels. Traffic separation lanes have been established in some congested waters with encouraging results, and wider usage of this technique is probable. Heretofore, use of these lanes has been voluntary; however, mandatory use may become a necessity.

Today, virtually all tankers are equipped with radar as an aid to navigation and most of the newer ships have two radars aboard. Sonar doppler equipment is rapidly becoming accepted as a valid navigational tool. The various shore-based surface electronic navigation devices (Loran, Decca, Omega) continue to improve, and satellite navigation, although inadequate at present, shows promise for the future. Increased emphasis is being placed at maritime schools on education and training in radar usage and interpretation.

Efforts have been made to utilize bridge-to-bridge communication in order to improve the safety of ship navigation in narrow water passages. Unfortunately, the development of bridge-to-bridge communication has been slowed by a failure to achieve international agreement and, in the United States, by labor jurisdictional disputes. IMCO has made recommendations which, if adopted, should help solve the problem.

Within the United States, the Coast Guard is seeking legislation to require bridge-to-bridge communication on all vessels above 300 gross tons navigating inland waters.

The Coast Guard is also presently revising the license examination for all ratings of deck and engine officers.

Nautical "rules of the road" will receive an emphasis of the highest priority at each level of examination. There is presently a proposal to require licensing of deck and engine officers on all commercial craft of 1,000 gross tons or less that ply U.S. inland and intercoastal waters. Vessels carrying passengers for hire are already so covered, but crew licensing requirements for all other craft will aid in raising industry standards.

Human error, which leads to accidents, can in many instances be attributed to insufficient training and lack of supervision.

There are at present no minimum educational and training requirements for ship crews geared to the size and the trade of the vessel. It is not uncommon to find crews of one or more nationalities and officers of one or more different nationalities with a serious personnel communication problem. The combination of the lack of technical training and language barrier is courting trouble of potentially disastrous proportions.

Virtually all U.S. labor unions maintain union-sponsored schools designed to keep their membership abreast of industry progress. Where deficient or lacking, improved education and training programs should have a high priority. However, there is presently no national school in the United States that provides training designed to the specific needs of our inland waterways, Great Lakes and rivers system. Such a national academy has been proposed and positive plans are being implemented. The U.S. Government is working with IMCO to help upgrade education and training on an international scale.

Mammoth Tankers. Industry has, from the beginning, been cognizant of the problems created by the mammoth tankers and has sought to understand and overcome them in a number of ways. One of the problems that was uppermost in the minds of the builders, owners and operators was the question of maneuverability and handling characteristics of these ships. Extensive model basin tests were conducted to obtain necessary design information and to improve techniques.

Unlike the aircraft industry, the marine industry had no training facilities to teach ship masters and pilots how to maneuver these huge vessels in confined waters. To overcome this deficiency, one of the major international oil companies set up facilities in Grenoble, France, where the problems of handling very large tankers are duplicated with small-scale, manned tanker models. The models operate on a lake equipped with buoys, docks, channels and other facilities specifically designed for these training procedures. The manned models are also instrumented to provide further realism in the technical aspects of the training. By combining the operation of models with classroom instruction, the student is provided with experience in the practical aspects of ship handling and knowledge of the latest technology and techniques. The facilities of this school are available to other oil companies that wish to participate. However, because there are no very large tankers of U.S. registry, participation by the U.S. seafaring community has been small.

Another ship-handling training aid has been very recently developed that operates on the principle of the Link trainer system used by the aircraft industry. The entire maneuvering procedure is electronically simulated, with the pilot operating from a mock ship's wheelhouse. However, since this training equipment is relatively new there has not yet been sufficient opportunity to assess its worth.

Techniques using electronic instruments have been developed to control the docking of mammoth tankers. The instruments very accurately measure the speed and distance of the vessel in relation to the dock, thereby eliminating the element of human judgment used in the past. This equipment should significantly reduce damage to both ship and berths caused by the vessel striking the dock when coming alongside.

D. Marketing of Products

1. Sources and Causes of Spillage and Wastes

For the purposes of examining sources, causes and methods of prevention of pollution by liquids or solids from petroleum industry operations, transportation of petroleum liquids by railway tank cars or trucks and terminal marketing or distribution practices can be conveniently examined together. Products distribution and transfer systems--whether they involve the familiar gasoline station of the petroleum industry or smaller airport fuel supply systems--involve the hauling of either special or limited-volume products to diverse destinations and transfer of liquids to tanks at the destination point.

Light-oil petroleum products are generally shipped from refineries to terminals and bulk plants, where they are stored in tank farms. Storage problems and preventive pollution measures are similar to those already described. These products are then transported by truck to service stations and commercial consumer accounts. At this point, gasoline is normally stored in underground tanks.

Major airports receive petroleum fuels by pipeline connected directly to one or more refineries or major ocean terminals. The fuels are transferred through hydrant fueling systems buried beneath the aircraft loading and service areas.

In loading and unloading light-oil petroleum products at terminals, bulk plants and service stations, spillage and resultant pollution can occur. Considering the billions of gallons transported each year, the incidence of spillage is minimal and is usually caused by human error.

Until recent years, underground storage tanks were fabricated from metal, which has an inherent tendency to corrode under certain soil conditions. Excessive corrosion could lead to tank leakage and possible rupture.[266]

Improper disposal of used lubricating oils and other liquid and solid petroleum wastes is a potential source for pollution that can be controlled. To date, such pollution has not created major problems.

2. Methods of Prevention

a) Equipment

Terminals are continually being provided with control equipment designed to reduce the possibilities of human error in truck loading and thus minimize the possibility of spillage. This equipment includes special connectors and couplings, valves, and sensing and automated mechanical devices. An estimated 10 percent of the Nation's 3,000 petroleum terminals have already installed some type of automated system designed to close down operations if valving and safety devices are not operating properly.[267] Expenditures for such systems at the remaining terminals were made at an accelerated rate during 1970 and are expected to continue for the next several years.

For many years, steel underground tanks have been used to store petroleum products at service stations. In the past several years, much has been done to reduce corrosion of these steel tanks and thereby prevent leakage.[268] Some of the methods used are--

- Protective covering of the tank, utilizing materials such as mastic, plastic or fiber glass
- Cathodic protection of the tank, utilizing anodes or a rectifier system.[269]

Since 1965, approximately 4,000 fiber glass tanks have been installed by 23 major oil companies in 39 states.[270] These tanks, made of fiber glass-reinforced plastic, are not subject to corrosion or similar deterioration and therefore eliminate the possibilities of leakage from this cause.[271]

Leak detectors are continually being improved and installed in service station systems to detect leaks between the underground tank and the dispenser nozzle.[272] Special valves with a sheer section and spring-loaded thermal-coupling are being installed which automatically eliminate the flow of product from the underground tank if the pump is moved or damaged, thus eliminating spillage or possible fire.[273] The API, in cooperation with a manufacturer, has developed equipment known as the "Tank Tightness Tester," which is able to determine within very close tolerance, if a leak exists in the system, whether it be underground tanks or the piping of the system.[274]

b) Operational Techniques

1) Prevention of Liquid Spills and Leakage

Special training courses and manuals are provided by the industry to instruct tank-truck drivers in the proper procedure for unloading petroleum products at service stations so as to control spillage.[275] The instruction includes, for example, gauging of the underground tanks, making properly tight connections, and inspecting vents, hoses, fittings, tank caps and control valves. The driver is instructed to be in a position to shut off the flow of liquid on a moment's notice, should it be necessary. Manual instructions are also provided on the proper procedures for removing spilled liquids if a spill should occur.

Petroleum companies also publish procedures for maintenance of service station equipment and make these publications available to most service station operators.[276] Industry procedures call for opening the pump housing once a week to check for leaks and to clean or replace strainers or filters. They also prescribe daily gauging of underground storage, both to provide an inventory check and to establish any abnormal loss of liquid. This daily check also helps to prevent over-filling when deliveries are made.

Dealer-training schools cover a variety of subjects, including safety precautions to prevent spillage. Pumps or dispensers are regularly inspected for possible leaks by dealers and maintenance personnel.

The American Petroleum Institute has a leak-detection program in effect, under the direction of each of its state offices, which is designed to determine the source of a leak when the source is not readily identifiable.[277] However, this program does not relieve an oil company of its responsibility for taking every means at its disposal to determine whether the leak is from one of its tanks.[278] If all companies involved have taken proper measures and are still unable to determine the source of pollution, contracts are made with specialists to do so. When the source is located, the company responsible for it must eliminate the leak and make proper repairs.

2) Disposal of Wastes

Provisions are made to collect spills that occur during loading of tank cars or trucks. Underneath the track, car or truck, a swing spout collects any drainage, diverting it into the waste-treatment system or a recovery collection basin.

The petroleum industry is increasingly focusing its attention on the proper disposal of used lubricating oils at service stations, as well as on the disposal of solid and liquid waste oil for its industrial customers. In addition, the industry is stressing good housekeeping practices by its service stations in the accumulation of used tires, batteries, and accessories for ultimate disposal so that the stations will be more aesthetically appealing and will not contribute to pollution of the areas by solid wastes.

There are means available for disposing of used lubrication oils if service station operators will collect and retain them. For example, the services of solid and liquid waste disposal contractors are available in some areas for removal of these wastes. However, in recent years the practice of re-refining waste oil has become economically unattractive, with a resulting decline in the number of refiners who were willing to collect liquid waste for this purpose. Heretofore, re-refining of waste oil had been a reasonably satisfactory method of dealing with the disposal of substantial quantities of waste lubricating oil. In recent years, however, this method, for a variety of reasons, has become economically unattractive and can no longer be considered a satisfactory method of coping with this problem. Therefore, about 3 years ago, the API initiated a program to investigate all possible avenues for proper waste-oil disposal.

It was found that there are limited satisfactory methods for ultimately disposing of these products and probably the most promising is blending with fuel oil as a boiler feedstock. Tests have shown that these oils can be burned economically, producing useful heat.[279] The problem deserves and is receiving continued study and action.

Efforts are also being made to reduce hazards and potential pollution encountered during cleaning operations of lead residues from storage tanks.[280] DuPont Corporation and Ethyl Corporation are assisting in cooperative projects to evaluate and put into effect better methods of disposing of sludge from leaded-gasoline storage tanks.[281] One method, also mentioned in the chapter on refining, is "weathering," or exposing the sludge to the atmosphere by spreading it thinly over the ground. Experience has shown that no long-term ground pollution problems result.[282]

Comprehensive programs for the disposal of used tires, batteries, accessories and containers in which petroleum products are packaged are also being initiated and implemented.[283] The aim of such programs is to improve the appearance of the station by eliminating untidy accumulations of used items. In many cases, enclosed areas are provided at service stations for the temporary storage of these items and of used automotive parts until they can be removed to permanent disposal areas.

In some major markets, where retreaded tires are in demand, programs have been initiated to pick up used tires for exchange to offset casing charges.

Disposal of used batteries is not considered a major problem at this time, as they represent a source of income to dealers. Used batteries are picked up by TBA distributors in many of the major markets, and dealers usually receive credit for the batteries at the current salvage value.

Dealer-training programs include instruction in good housekeeping practices to maintain acceptable service station appearance, and constant surveillance and inspections are carried out by oil company representatives with similar intent. These efforts are supported by surveys such as The DuPont Service Station Observation Study, as well as by beautification contests at both the local and national levels.

Section 3.
AIR POLLUTION CONTROL

A. Storage of Oil and Gas

1. Sources of Vapors

There are certain air contaminants associated with the storage of oil and gas, but the control methods now developed and in general use are capable of sufficiently reducing or eliminating their emission into the atmosphere.

Hydrocarbon vapor losses are the principal contaminant. In addition, objectionable odors may be caused by emissions of sulfur or nitrogen compounds. Emissions from storage vessels are generally caused by evaporation of liquids or boil-off of liquefied gases. To understand how losses can occur during storage, it is necessary to introduce the concept of vapor pressure.

When a volatile liquid is introduced into an air-filled fixed-roof tank, a small portion of liquid vaporizes to saturate the vapor space above the liquid. The fraction of hydrocarbon vapor relative to air in the confined vapor space will depend on the vapor pressure of the liquid being stored. As air is pulled in through the tank vent, which occurs when the vapor space cools or when liquid is withdrawn from the tank, additional liquid vaporizes to saturate the air introduced. Conversely, as saturated gas is expelled through the tank vent, which occurs when the vapor space warms up or when liquid is added to the tank, a portion of the expelled gas is hydrocarbon. Hydrocarbon emissions from storage tanks due to temperature fluctuations are termed *breathing* losses to differentiate them from filling losses. Since breathing losses are small in relation to filling losses, hydrocarbon emissions from fixed-roof storage tanks are closely related to throughput. Table 28 lists the common petroleum products and their vapor pressures.

Basically, then, the volatility of the stored substance governs the release of vapors and odors. Heat is the prime factor in the vaporization of a volatile liquid, and the rate of evaporation is influenced by weather conditions and atmospheric temperature, tank-shell temperature, vapor-space temperature, and

TABLE 28

VAPOR PRESSURE OF PETROLEUM PRODUCTS

Material	Vapor Pressure
Crude Oil	2* psia at 60° F
No. 2 Distillate Fuel Oil	†
No. 6 Residual Fuel Oil	†
Turbine Fuel	†
Aviation Gasoline	2.5 - 3.0 psia at 60° F
Motor Gasoline	4.0 - 6.0 psia at 60° F
Butane	26.0 psia at 60° F
Propane	105.0 psia at 60° F
Methane	100 psia at -206° F 50 psia at -227° F

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* This is the National Average, but the vapor pressure is quite variable because of the presence of light materials dissolved in the otherwise nonvolatile, heavy components.

† Negligible vapor pressure, i.e., less than 0.1 psia.

liquid body and surface temperature. Calculation of evaporation losses is dependent upon these variables and the type of storage facility involved. The evaporation loss from fixed-roof tanks containing light crude oil, for example, has been estimated at 0.05 barrels per day for each 1,000-barrel storage capacity. The American Petroleum Institute has published several bulletins dealing with evaporation losses.[284]

Filling operations and vapor space also influence the emission of vapors and odors from storage facilities. The rate and quantity of contaminant emissions are directly proportional to the rate at which the liquid is charged to the vessel.

The boil-off from liquefied natural gas (LNG) varies according to the type of storage facility, the amount of insulation used and the size of the container. It has been estimated that the daily average boil-off of LNG ranges from 0.04 percent to 0.20 percent per total storage volume.

2. Types of Storage Facilities

The type of storage facility required will depend primarily upon the volatility of the material to be stored. Storage facilities may be considered either as "closed-storage" or as "open-storage," depending upon the stored material's exposure to the atmosphere.

a) Crude Oil and Liquid Products

For the storage of crude oil and liquid products, the primary closed-storage facilities are fixed-roof tanks, floating-roof tanks, conservation tanks and pressure vessels. The open-storage facilities include reservoirs which were developed to store large quantities of residual oils and fuel oils, open tanks, pits and ponds, which are no longer used by modern petroleum operations in the United States due to safety, conservation and housekeeping factors.

1) Fixed-Roof Tanks

The standard fixed-roof tank is vertical and cylindrical, and operates at atmospheric pressure or slightly above. It may have a flat, recessed, conical or domed roof.

2) Floating-Roof Tanks

The floating-roof tank is used for storing volatile material such as gasoline in the low (4 to 12 psia) vapor-pressure range. It may be described as a pan, pontoon or double-deck floating-roof tank. The horizontal roof floats directly at the liquid surface and is sealed at the periphery, thereby avoiding formation of a vapor space and eliminating breathing and filling losses.

If we look, for example, at storage in a fixed-roof tank of motor gasoline having a true vapor pressure of 5 psia, the saturated vapor in the vapor space would be represented by 5 psia hydrocarbon out of the total atmospheric pressure of 14.7 psia, or about one-third of the saturated vapor expelled during breathing or filling would be gasoline vapor. For this reason, most large gasoline storage tanks, such as would be found at most refineries, are of the floating-roof type.

Petroleum products less volatile than gasoline are stored in a number of ways, depending on local conditions and throughput quantities. Aviation gasoline, for example, with less than half the volatility of motor gasoline, is stored in fixed-roof tanks, except where high throughputs call for the use of floating-roof tanks. Despite its low volatility, turbine fuel is usually stored in floating-roof tanks to keep it free of atmospheric contaminants. Furnace oils (No. 2 and No. 6 fuels), being essentially nonvolatile, are stored in fixed-roof tanks. Crude oil has an extremely variable vapor pressure depending on the concentration of light hydrocarbons, and consequently, storage varies from open tanks to floating-roof tanks.

Studies generally show that the contribution of smog-forming reactive hydrocarbons from petroleum storage tanks is so small that controls for pollution reasons can seldom be justified. Controls usually take the form of floating-roof tanks or vapor-recovery systems.

3) Conservation Tanks

Conservation tanks include those tanks with lifter-roof and internal, flexible diaphragms or internal, plastic floating-blankets. The principle of emissions control by plastic floating-blankets is the same as that of floating-roofs. This type of tank may be used as a vapor surge tank if manifolded to the vapor space of fixed-roof tanks.

4) Pressure Vessels

Products more volatile than gasoline, such as butane and propane, are stored in closed pressure-vessels. Methane, which is the major component of natural gas, is stored either as a gas in gas holders or as a cryogenic liquid in low-temperature vessels.

Pressure vessels contain the vapors or odors by operating at pressures effectively above the vapor pressure of the stored material. They are designed in different shapes to operate at various pressures above atmospheric, as indicated in Table 29.

TABLE 29

CHARACTERISTICS OF PRESSURE VESSELS

Shape of Vessel	Operating Pressure
Horizontal, Cylindrical	Various (depending on Product Vapor Pressure)
Spheres	Up to 217 psig
Spheroids	Up to 50 psig
Noded Spheroids	Up to 20 psig
Hemispheroids	Up to 15 psig
Noded Hemispheroids	Up to 2.5 psig

b) Liquefied Gases

Storage facilities for liquefied gases must all be the closed-storage type. For the storage of LPG, large high-pressure vessels are used above ground; in addition, underground and refrigerated storage facilities have been developed. Most of the underground storage areas have been formed by the leaching of salt beds or domes; but where salt sections were not available, caverns have been mined in limestone, shale and granite. Depleted oil and gas fields or aquifers are also being used.

LNG requires the use of refrigerated storage facilities, as do some LPG products. LNG storage facilities can be placed either above or below ground level, depending upon the type of cryogenic container used. The following types of containers are currently being used:

- Double-wall metal tanks
- Prestressed concrete tanks
- Frozen holes
- Mined caverns.

The natural gas industry also utilizes underground reservoirs, which are filled during low demand and emptied during high demand.

Another means of storage commonly used is "line pack," where natural gas is packed into transmission lines at certain pressures depending upon the design of the facilities. Other storage facilities, which are used primarily by gas distribution companies, include bottle or pipe-type holders which are manifolded and usually placed underground and spheres and cylinders located above ground. The use of these storage facilities is not widespread.

3. Methods of Control

The control of emissions from oil and gas storage facilities serves three purposes:

- The reduction or elimination of air contaminant emissions
- The reduction or elimination of fire hazards
- The recovery of valuable products.

The following paragraphs discuss the major methods used to control the emission of vapors and odors.

a) Related Systems and Procedures

Several methods of controlling emissions of vapors and odors from gas and oil storage facilities are generally used in conjunction with the storage facilities just described.

1) Variable-Vapor-Space Systems

As the storage tanks are filled or emptied or when the temperature changes, vapors from one or more storage tanks are displaced into and out of a special tank provided to hold these vapors. Excess vapors are piped into a fuel system or to a smokeless flare for incineration.

2) Vapor-Recovery Systems

These systems operate similarly to variable-vapor-space systems, except that certain substances in the emissions are recovered. The excess vapors are compressed and fed into an absorption unit for recovery of the condensable hydrocarbons. The noncondensables are either piped into a fuel system or to a smokeless flare for incineration. The feasibility of this type of control is dependent on the proximity of a process unit.

3) Materials and Equipment

Utilization of selected materials and equipment can assist in controlling emissions. For example, a plastic foam blanket has been proposed as a means of reducing evaporation losses.[285] Also, the proper paint for the tank shell and roof provides a protective coating which influences the vapor and liquid temperatures. Breathing emissions can be reduced as much as 25 percent by the use of aluminum paint rather than black paint, and 25 percent by the use of white paint rather than aluminum paint.[286] Emissions can also be reduced by using remote gauges and sampling devices so as to eliminate the need to open tank gauge hatches for level reading and sampling.

4) Procedures

Scheduling liquids into and out of storage tanks so that they are pumped in during cool hours, withdrawn during warm hours and pumped at short time intervals can reduce emissions. Maintenance of pumps, valves and tank accessories can reduce and possibly eliminate leakage.

B. Transportation of Oil and Gas

1. Sources of Vapors

Hydrocarbon vapors are the major contaminants associated with the transportation of crude oil, petroleum products, natural gas, LPG and LNG. Their emission occurs primarily during filling operations of the tank-type carriers.

The loading of motor gasoline ordinarily produces relatively the greatest concentration of hydrocarbon vapors. The hydrocarbon concentration in the vapor phase has been estimated to be 20 to 50 percent by volume. Table 30 gives a typical analysis of vapors from the bulk loading of gasoline into tank trucks.

TABLE 30

VAPOR ANALYSIS OF GASOLINE BULK LOADING

Fraction	Volume (Percentage)		Weight (Percentage)	
Air		58.1		37.6
Hydrocarbons				
Propane	0.6		0.6	
Iso-butane	2.9		3.8	
Butene	3.2		4.0	
N-butane	17.4		22.5	
Iso-pentane	7.7		12.4	
Pentene	5.1		8.0	
N-pentane	2.0		3.1	
Hexane	3.0	41.9	8.0	62.4
TOTAL		100.0		100.0

Source: HEW, *Air Pollution Engineering Manual,* PHS Publication No. 999-AP-40 (Cincinnati, Public Health Service, 1967).

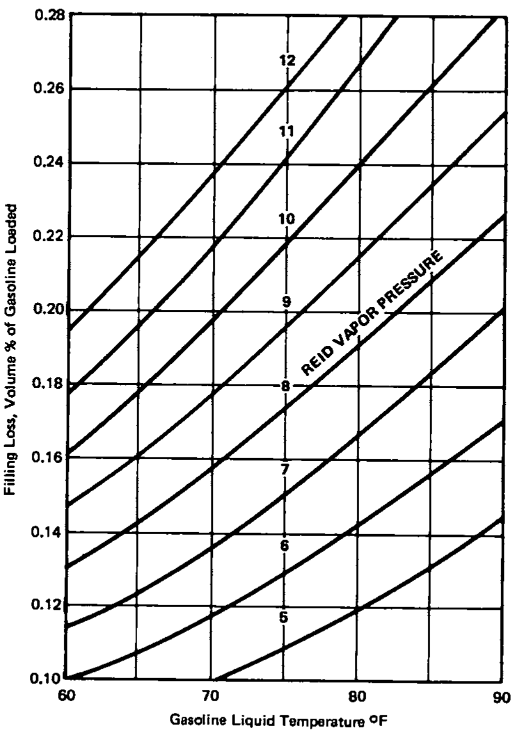
Vapor losses from the overhead loading of tank vehicles, on the basis of a 50-percent splash-filling operation, amount to 0.1 to 0.3 percent of the volume loaded. Figure 58 presents a correlation of loading losses with gasoline vapor pressures.

2. Methods of Control

There are two types of filling operations for tank-type carriers: bottom loading and overhead loading. The bottom-loading method causes hydrocarbon vapors to be displaced as the tank is filled. The overhead-loading method uses either a submerged or a splash-filling technique. Splash-filling generally increases the hydrocarbon vapor concentration. Naturally the type of loading operation influences the amount of hydrocarbon vapors emitted. Marine tankers are usually filled using the bottom-loading method, but tank vehicles and rail tank cars use both bottom- and overhead-loading methods.

The control of vapor emissions during loading operations requires a method of collecting the vapors at the hatch or vent opening and a method of disposal. Various types of collectors have been developed and have proved to be effective. The vapors can be used as fuel, processed for the recovery of hydrocarbons, used in conjunction with a vapor balance system, or vented and incinerated in a smokeless flare. The type of disposal depends on the proximity of facilities that can use or process the vapors. Vapors from loading installations distant from processing facilities can also be recovered by the use of package units. One type of unit absorbs hydrocarbon vapors in gasoline; another type adsorbs the hydrocarbon vapors on activated carbon.

The technology necessary to control the emission of contaminants associated with the transportation, other than by marine tanker, of petroleum products, crude oil, natural gas, LPG and LNG is available and in general use, thus helping to combat the air pollution problem.



Source: HEW, *Air Pollution Engineering Manual* (Public Health Service, 1967), p. 635.

Figure 58. Correlation of Tank Vehicle-Loading Losses (50% submerged filling) with Reid Vapor Pressure and Liquid Temperatures of the Motor Gasoline.

C. Marketing of Petroleum and Products

1. Sources of Vapors

The only air pollutants of concern in the marketing of petroleum products are hydrocarbon vapors. The more volatile products handled by marketers, such as automotive and aviation gasoline and LPG, are essentially free of nonhydrocarbon components.

In any discussion of marketing pollution potential, the product of primary significance is automotive gasoline. Aviation gasoline, because of the small volumes involved and the relatively low volatility, is of secondary importance. For example, in 1970, the consumption of aviation gasoline was 0.93 percent (see Vol. One, Table 12, p. 79) or less than 1 percent of the consumption of automotive gasoline. In addition, a typical true vapor-pressure of aviation gasoline will be around 2.5 psia, as compared to about 5 psia for automotive gasoline. A product of lower volatility will have lower handling and evaporation losses, all other things being equal.

All sources of potential hydrocarbon emission from service station operations are considered in this report. Hydrocarbon losses to atmosphere during transportation of gasoline from the terminal to the service station are negligible.[287] However, losses can occur (1) as a result of the transport (usually a truck) being emptied at the station, (2) from the underground storage tank of the service station, and (3) during the refueling of each customer's automobile gasoline storage tank.

For a system not using vapor recovery, these losses, expressed as percent by volume of the gallonage handled, are estimated as follows:

	Percent
Truck Unloading	0.067*
From Underground Tank	0.200
Auto Tank Refueling	0.200
TOTAL	0.467

Each of these sources of hydrocarbon loss is discussed below, along with the basis for the estimate of percentage loss given above.

a) Truck Unloading

Upon arrival at the service station, the gasoline is emptied from the transport truck through hoses into underground storage tanks. As the liquid gasoline is unloaded from the truck, air is drawn into the compartment, and some gasoline liquid will evaporate to partially saturate this air. An API study has shown that the vapor space in the truck reaches only about one-third of saturation with gasoline vapor by the time the liquid load is emptied.[288] This air/hydrocarbon mixture in the truck is not lost until it returns to the terminal for reloading. Thus, the gasoline vaporized inside the truck during unloading at the service station represents only about one-third of the gasoline vapor displaced during the refilling of the truck at the terminal.

Arthur D. Little, Inc., extended the results of the API report and estimated that the vapors retained in the truck after unloading at the service station amounted to 0.067 percent of the total load.[289]

b) Underground Service Station Tanks

A number of studies have been conducted, and others are in progress, to determine the magnitude of the individual losses of materials at the service station.

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*Physically displaced to the truck vapor space and lost when reloaded at the terminal.

As liquid gasoline from the transport truck enters the underground storage tank at the service station, tank vapor is displaced to the atmosphere. This vapor is generally found to be saturated with gasoline vapor, as it has normally spent a reasonably long time in contact with liquid gasoline.

As gasoline is delivered to the automobile at the dispenser, air is drawn into the underground tank, through a vent pipe, to fill the empty space. In time, enough gasoline liquid will evaporate to saturate the air introduced. This is the gasoline vapor which will be expelled during any following filling step. This loss is called filling loss. Small losses would also occur as a result of changes in temperature of the underground tank. These are usually referred to as breathing losses. The magnitude of tank breathing losses is minor. In fact, in the Los Angeles report of 1963, more than 90 percent of the daily hydrocarbon emissions from underground storage tanks was attributed to the tank filling operation.[290]

Arthur D. Little has estimated that 0.2 percent by volume of gasoline handled represents the hydrocarbons lost to the atmosphere when underground service station tanks are splash-filled. Los Angeles estimated this same loss at 0.185 percent by weight.[291] The Los Angeles estimate, by volume, would be slightly higher than 0.2 percent. However, it should also be noted that many of the existing service stations have underground tanks equipped with submerged filling devices in place of splash-filling. With submerged fill, the loss by volume would be in the neighborhood of 0.12 percent. For purposes of this report, the figure of 0.2 percent has been used.

c) Refueling of Automobile Fuel Tanks

When the automobile is refueled, hydrocarbon losses occur because of (1) displacement of vapor from the fuel tank, (2) entrainment of liquid droplets, (3) accidental spills, and (4) post-fill nozzle losses. These losses are commonly referred to collectively as "refueling loss."

Scott Research of San Bernardino, California, is currently studying the automobile refueling operation. Their work, which is being done for the Coordinating Research Council, will provide additional data on percentage refueling losses. For the purposes of this report, the value of 0.2 percent by volume developed by Arthur D. Little has been utilized.

d) Nationwide Service Station Loss

In order to arrive at a nationwide hydrocarbon loss for service stations, the 1968 retail automotive gasoline throughput is used, as follows:

$$\frac{56{,}435{,}000{,}000^{*} \quad (.00476)(218)}{(42) \quad (2{,}000) \quad (365)} = 1{,}910 \text{ tons per day.}$$

Applying this service station loss percentage to gasoline throughputs for selected areas obtains the following round numbers as a general basis for comparison:

	Tons per Day
State of California	190†
State of New York	130
Los Angeles County	100†
City of New York	30
State of Maine	10
District of Columbia	5
Manchester, New Hampshire	1

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*Source: *National Petroleum News* (May 1969).

†Assumption is made that underground tanks at service stations are splash-filled.

It should be noted that the above hydrocarbon emissions at the service stations are responsible for only about 3 percent of total hydrocarbon emissions from all sources in urban areas where there are no controls. The hydrocarbon emissions from the gasoline-powered motor vehicle, including exhaust, blowby and evaporation losses, account for about 52 percent of the total in urban areas having no controls.[292] The balance, or about 46 percent, is emitted from other petroleum facilities, chemical plants, organic solvent utilization, combustion of fuels, incineration and aircraft.

e) Losses--Data and Significance

An adequate amount of data is available on hydrocarbon losses to the atmosphere as trucks deliver gasoline to the underground service station tank. Better information and data are needed, however, to quantify the loss which occurs as the automobile or truck is refueled. CRC and EPA are currently in the process of obtaining better data.

As the large sources of hydrocarbon emissions are brought under control in those areas experiencing acute air pollution problems, the marketing loss will become relatively more significant. If they become of concern in specific areas, these losses may have to be locally controlled.

2. Methods of Control

The various processes to convert hydrocarbon vapors back to a liquid--such as absorption, adsorption, compression and refrigeration--are basically impractical for use at the typical service station. These devices represent complicated engineering equipment beyond the operating capability of typical service station personnel. In one study in Los Angeles, an experimental adsorption unit using activated charcoal proved to be unsatisfactory because of the heat of adsorption.[293] A complete incineration unit would also be impractical for use at the service station because of space limitations at floor level and the safety hazard.

a) Vapor-for-Liquid Concept

One interesting concept for controlling hydrocarbon emissions at the service station which has been investigated is vapor-for-liquid recycle. In this case, as liquid gasoline is removed from a tank or a compartment, hydrocarbon vapors are added to fill up the empty space. Air would not normally be admitted to this closed system. At a service station, and with a completely integrated system, the following would take place:

- As gasoline is added to the automobile's fuel tank, the displaced vapors are returned to the underground tank.
- As gasoline is unloaded from the transport to the service station's underground tank, the displaced vapors are returned to the transport truck.
- A truck full of gasoline vapor is returned to the bulk plant or terminal.
- As the transport is loaded with gasoline, vapors are again exchanged for the liquid or are returned to a vapor-recovery system.

Reference is made to Figure 35 of Chapter Five, "Refining," for a pictorial description of the vapor-for-liquid recycle system.

If an integrated vapor-for-liquid recycle system were to be installed in an area having serious air pollution problems, to be fully effective all of the service stations would have to be revised or converted, and all oil company and for-hire trucks would have to be converted to provide a closed system. In most cases the supplying refineries, bulk plants and terminals would have to install vapor-recovery units. At the automobile service station interface, refueling nozzles capable of excluding air during refueling and redirecting displaced gasoline vapor back to the underground tank would have to be developed. Several equipment suppliers have attempted to develop such a nozzle, but to date their efforts have not been successful because of the many different configurations of fill pipes on automobile fuel tanks.

In 1962, the Los Angeles Air Pollution Control District studied a limited vapor-for-liquid recycle system.[294] It involved a closed system and the truck delivery of gasoline to a service station. Vapors were returned to the truck as gasoline was delivered to the underground tank. A number of pertinent conclusions were developed, including the following:

- Ninety percent of the daily hydrocarbon emissions from underground storage tanks is attributed to tank-filling operations.
- Control of the filling operation is the key to control of hydrocarbon emissions from underground gasoline storage tanks.
- All other things being equal, splash-filling of an underground tank can produce double the emissions of bottom-filling.

As a result of this report, Los Angeles decided to require that all service station underground tanks with a capacity of 2,000 gallons or more be equipped with a submerged fill pipe, with offset remote fill exempted.

b) Retention of Displaced Vapors in the Automobile

Another avenue that could be taken to reduce refueling losses would be to adsorb the displaced vapors in the automobile, such as by use of carbon canisters. Here again, automobile filling nozzles would have to be standardized to prevent displacing vapors to the atmosphere during refueling. One important advantage of this approach would be that no problem could arise with local governmental standards agencies, in that vapor displaced from the automobile gasoline tank would remain in the custody of the vehicle owner. However, facilities must be provided to regenerate the canister or dispose of it after use.

c) Elimination of Fuel-Tank Vapor Space

Another possible solution for dealing with the refueling loss problem would involve the elimination of the fuel tank's vapor space. A flexible diaphragm could be installed in the fuel tank. Work in this field was done by Union Oil in 1966.[295] The diaphragm, by floating on the gasoline, eliminates the vapor space and, therefore, the refueling loss.

d) Areas for Technological Emphasis

One significant forward step would be to develop a single standard fill-pipe configuration for the gasoline-powered vehicle. Groups such as the Society of Automotive Engineers could provide an appropriate mechanism for such a development.

Efforts could also be usefully directed toward utilizing new or existing equipment on the automobile to capture vapors displaced during the refueling operation. Useful research could likewise continue on the flexible-diaphragm fuel tank or an equivalent device that would eliminate the fuel-tank vapor space.

In general, the technology exists for implementing a vapor-for-liquid recycle system but questions remain as to its cost-effectiveness.

Chapter Seven

MAJOR OIL SPILLS

Oil spills, large and small, have long been of concern. It is probable that the best training, procedures and prevention facilities will not be 100 percent effective in eliminating oil spills. Spilled oil cannot be hidden or ignored. Cleaning up an oil-contaminated and oil-fouled area is costly and time consuming. Public reaction to oil spills is understandably strong and may bring about unnecessarily restrictive legislation.

Unfortunately, mechanical and human failure and the vagaries of nature, which are not readily subject to legislative control, may cause a spill of significant proportions. Two highly publicized and thoroughly studied major spills (the *Torrey Canyon* and Santa Barbara) served, in recent years, to draw worldwide attention to the prevention and control of such incidents. These are illustrative and serve as examples for discussion.

On March 18, 1967, the tanker *Torrey Canyon,* loaded with 119,000 tons of Kuwait crude, ran aground on the Seven Stones Reef off the southwest coast of England. It has been reported by the British that 30,000 tons of crude escaped to the sea, initially. During the next 7 days, another 20,000 tons were lost. On March 26, the *Torrey Canyon* broke up during salvage operations and released approximately an additional 50,000 tons. Thus about 700,000 barrels of crude oil were spilled into the sea.

On January 28, 1969, during normal development of a prospective petroleum-bearing oil pool on the Rincon structural trend about 6.5 miles southeast of Santa Barbara, California, a gas blowout occurred during completion of an offshore well. Until February 7, when the well was killed by cementing, uncontrolled flow led to local oil pollution. Reservoir damage during this period caused a subsequent moderate and steady oil seepage from the sea floor, estimated to be at a daily average rate of 30 barrels, that, in turn, caused a continual slick on the surface. This seepage was substantially reduced by early September 1969 to less than 10 barrels per day, as a result of a drilling and grouting program.

Section 1.
CONDITIONS ATTENDANT TO SPILLS

These incidents have led to a marked proliferation of attempts by private citizens, governments and industry to analyze the factors which can cause major spills so that the possibility of their occurring can be further reduced, and, if they do occur, they can be controlled.

The first step in determining a feasible approach for controlling massive oil spills in open waters is an understanding of the conditions attendant to such spills, i.e., their major characteristics, where they are likely to occur and how they are affected by the environment. Dillingham Corporation, at the request of the American Petroleum Institute, has made (a) an analysis of past major spills, (b) a delineation of geographic regions of primary importance, and (c) an analysis of the environmental characteristics which could affect and be affected by oil spills. Oil spill control methods, equipment and materials are also discussed.[296]

A. Relevant Facts About Past Major Oil Spills

Classification of an oil spill as *major* or *minor* is a value judgment usually based on the volume of oil spilled. Numerous leaks, spills and seepages of varying volumes have been recorded. Dillingham chose to limit their discussion to spills over 2,000 barrels and to label them "major."

Information has been compiled on 38 major spills which occurred during the period 1956-1969. The examination included the location of the incident, the crude petroleum or product involved, the quantity of materials, the rate of spillage, the nature of any water or shoreline contamination that resulted, the duration of the incident, the weather conditions during the incident, the type of shoreline affected, and the control approach that was employed.

Analysis of these 38 spills defined the nature and magnitude of the problems presented by a large oil spill and the capabilities required in a control system for it to be effective against such a spill. This analysis also provided information on the performance of control items which had been used in the past and which, to a large extent, are all that are available today.

Although the emphasis was on spills of 2,000 barrels or more involving heavy oil in offshore waters, information was also collected on various other incidents, including (a) large spills involving other than heavy oils where they occurred in open water, (b) spills of less than 2,000 barrels where the incident received wide public attention, and (c) several spills in inland waters where valuable documentation was available. Table 31 lists the significant characteristics and common aspects of the oil-spill incidents considered in the evaluation.

The results of this graphic comparison of past spill incidents with respect to specific characteristics such as source, composition of material spilled, volume, distance from shore, duration of the spill, extent of coastal contamination, type of coastline utilization, and distance of incident from the nearest port are shown in Figures 59 through 66.

An examination of the source of 36 major oil spills indicates that 75 percent were associated with vessels--of these, over 90 percent involved tankers and half were the result of tanker groundings (Figure 59). This implies that future spills are likely to be caused by vessels. As tankers continue to increase in size, the number of tankers operating may decrease.

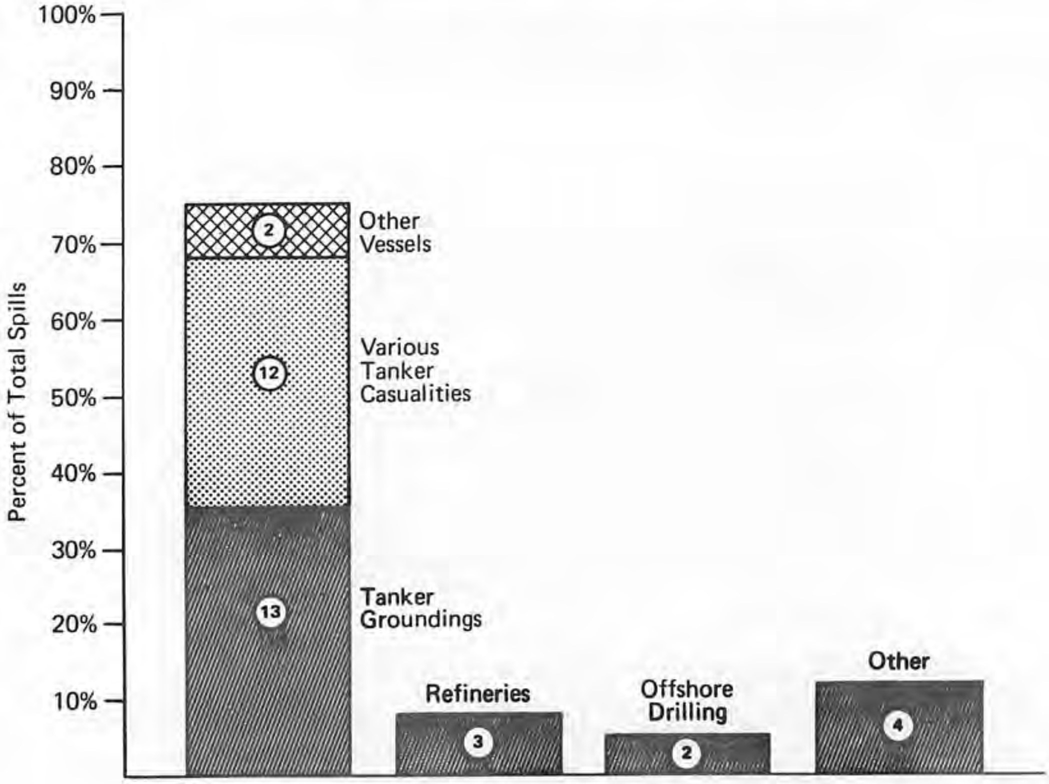

Figure 59. Source of Spill (Data from 36 Incidents).

These new, larger tankers are fitted with the latest navigational and operational equipment and are manned by more qualified and better trained personnel. This reduction in traffic and improvement in tanker operations will reduce the possibility of another massive spill.

The Dillingham study did not document any significant spills from offshore pipelines. As for the composition of material spilled, of the 2,230,000 barrels of oil spilled in 35 incidents included by Dillingham in this analysis, 80 percent was crude, 19 percent was light oil, and 1 percent was residual oil (Figure 60). Not only did crude oil represent the largest volume of material spilled, it was also the material involved in the most incidents--18 of the 35 spills examined involved crude. Residual oils were involved in the next largest number of spills (14 out of the 35 documented). These 14 spills, however, resulted in only 34,000 barrels or the already noted 1 percent of total spill volume. Thus, crude and residual oils appear most likely to be involved in future spills.

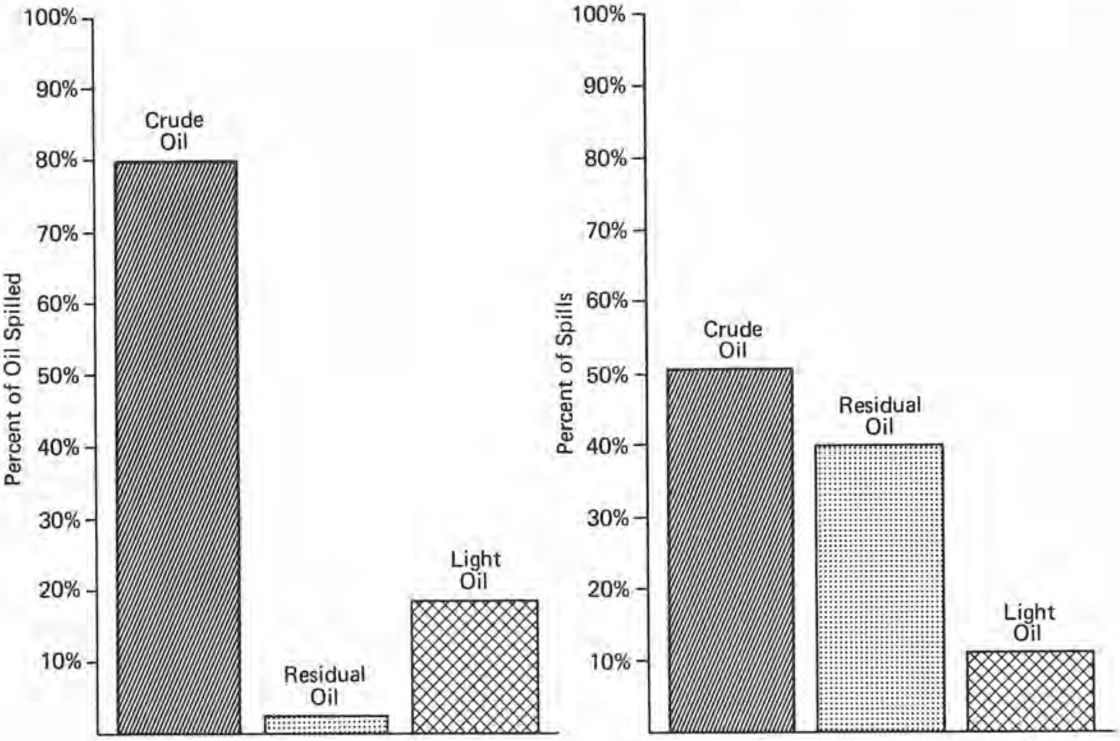

Figure 60. Composition of Material Spilled (Data from 35 Incidents).

The data on volume of material spilled indicate that in 23 coastal spills, where spill volume greater than 2,000 barrels was recorded, quantities ranged from 2,000 barrels to a high of 700,000 barrels in the case of the *Torrey Canyon* (Figure 61). The median volume is approximately 25,000 barrels, and 50 percent of the spills lie between 5,000 and 100,000 barrels (this last figure being the reported size of the Santa Barbara spill). Further, 70 percent of the spills were over 5,000 barrels, whereas only 15 percent exceeded 200,000 barrels.

Distance from the shoreline is a significant factor in that this information provides an indication of the length of time available for mobilizing shoreline protection before the oil may reach the shore. Of the offshore spills, 50 percent occurred less than 1 mile from shore, and 80 percent were within 10 miles of the shoreline (Figure 62). Since oil appears to drift at 3.3 percent of wind velocity, with an assumed average wind of 15 knots the oil slick

TABLE 31

MAJOR OIL-SPILL INCIDENTS--SIGNIFICANT CHARACTERISTICS

Name	Date	Cause of Spill	Material	Volume (Barrels)	Distance from Shore (Miles)	Coastline Utilization*	Extent of Contamination (Miles)	Distance from Port (Miles)	Duration (Days)
Algol, tanker	02-09-69	Grounding	#6 F.O.	4,000	3	H, R	None	<10	21
Andron, tanker	05-05-68	Sinking	Crude	117,000				>50	
Anne Mildred Brovig, tanker	02-20-66	Collision	Crude	125,000		R			75
Argea Prima, tanker	07-17-62	Grounding	Crude	28,000		H, R	15		
USS Bach (DDE-470)	02-06-68	Grounding	NSFO		<1	R	None	<10	23
Benedicte, tanker	05-31-69	Collision	Crude	14,000	13	R	Minor	10-25	13
Chryssi P. Goulandris, tanker	01-13-67		Crude	2,600	<1		Moderate	<10	
Dutch Coast Spill	02-16-69	Unknown	Residual	1,000			Moderate		
Esso Essen, tanker	04-29-68	Grounding	Crude	30,000	3		15		7
Fawley, refinery	01- -61	Pumping	Crude		<1		Moderate		
General Colocotronis, tanker	03-07-68	Grounding	Crude	30,000	2	H, R	Moderate		60
Hamilton Trader, tanker	04-30-69	Collision	Residual	5,000		H, R, I	45		90
Hess Hustler, tank barge	11-12-68	Grounding	#6 F.O.	40	<1	R		25-50	5
Humboldt Bay, refinery	12- -68	Hose Failure	Diesel	1,400					
Kenai Peninsula, tanker	11-05-68	Collision	Crude	1,000	<1	I	Minor	<10	2
Keo, tanker	11-05-69	Hull Failure	#4 F.O.	210,000	120		None	>50	
Martita, tanker	09-20-62	Collision	Bunker C	4,300	<1	H, R, I		<10	
Moron, refinery	03-29-68	Pumping	Crude	16,000	<1	R	6	<10	5
New Castle, power station	1963-65	Leak	Residual	40	<1	I	Moderate	<10	
Ocean Eagle, tanker	03-03-68	Grounding	Crude	83,400	<1	R, I	16	<10	65
Palva, tanker	05- -69	Grounding	Crude				5		
Pegasos, tanker	02-08-68	Hull Failure	Bunker C		270		None	>50	13
P. W. Thirtle, tanker	09-01-60	Grounding	Bunker C		2	H, R, I	Extensive	10-25	
R. C. Stoner, tanker	09-06-67	Grounding	Mixed	143,300	<1	R, I	Extensive	>50	10
Refinery Loading Site	1962	Hose Failure	Crude	2,000	<1	I	25	<10	55
Robert L. Polling, tank barge	05-10-69	Collision	#2 F.O.	4,700	<1	H, I	13		1
Santa Barbara, platform	01-28-69	Natural Faults	Crude	100,000	6	H, R	40	<10	<100
Seagate, tanker	09-06-56	Grounding	Residual					45	
Seewarren, storage tank	11- -69	Tank Failure	Crude	200,000	<1			<10	
Ship Shoal, drilling rig	03-16-69	Storm Shifting	Crude	2,400	6		None		3
USS Shangri-La (CVA-38)	1965	Pumping	NSFO	200		R	Moderate		3
Tampico, tanker	03- -57	Grounding	Diesel	60,000	<1		3	>50	
Tim, tank barge	02-18-68	Sinking	#6 F.O.	7,000	<1	I	Moderate		13
Torrey Canyon, tanker	03-18-67	Grounding	Crude	700,000	15	H, R	242	25	30
Waikiki Beach	04-21-68	Unknown	Bunker C		<1	R	7	<10	4
Waterford Beach	01-18-69	Unknown	#6 F.O.		<1	H, R, I	20		10
Witwater, tanker	12-13-68	Hull Failure	Mixed	15,000	<1	R, I	Extensive	<10	
World Glory, tanker	06-13-68	Hull Failure	Crude	322,000	40	R	None	>50	20

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* H=Residential Housing; R=Recreational; I=Industrial.

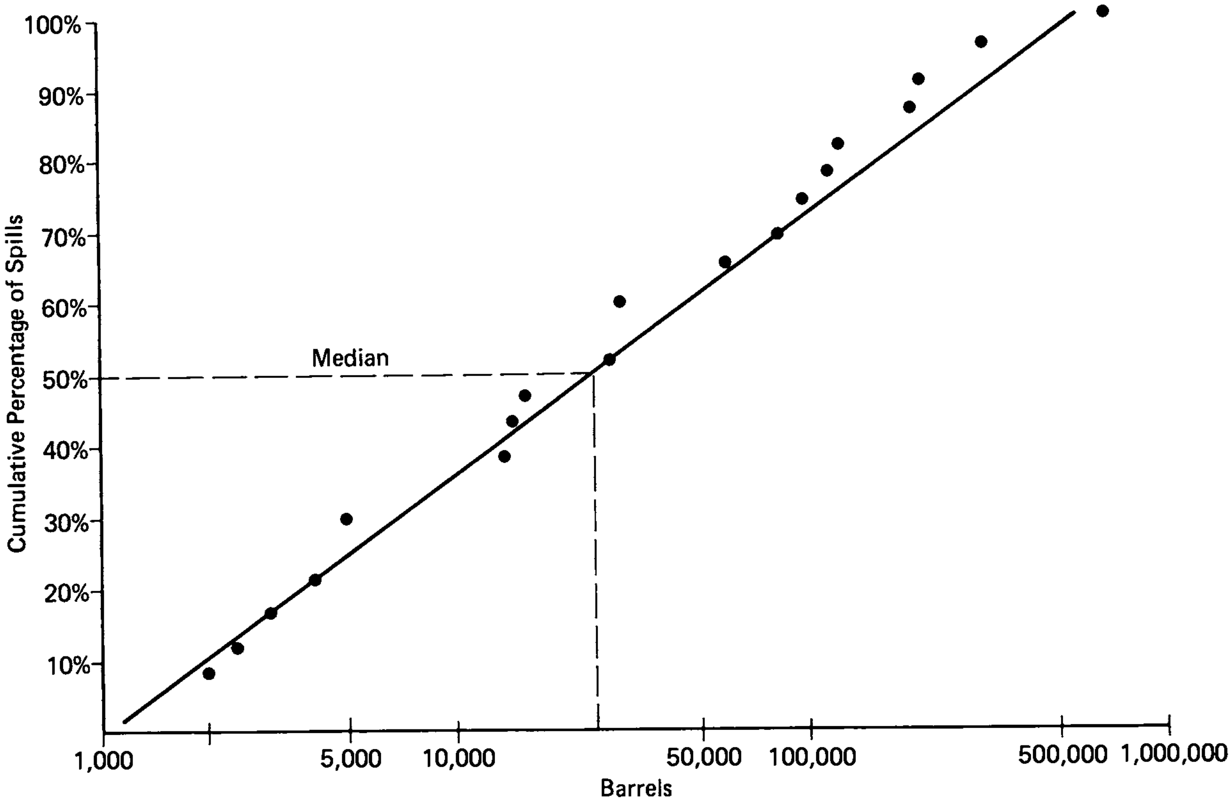

Figure 61. Volume of Spill (Data from 23 Incidents).

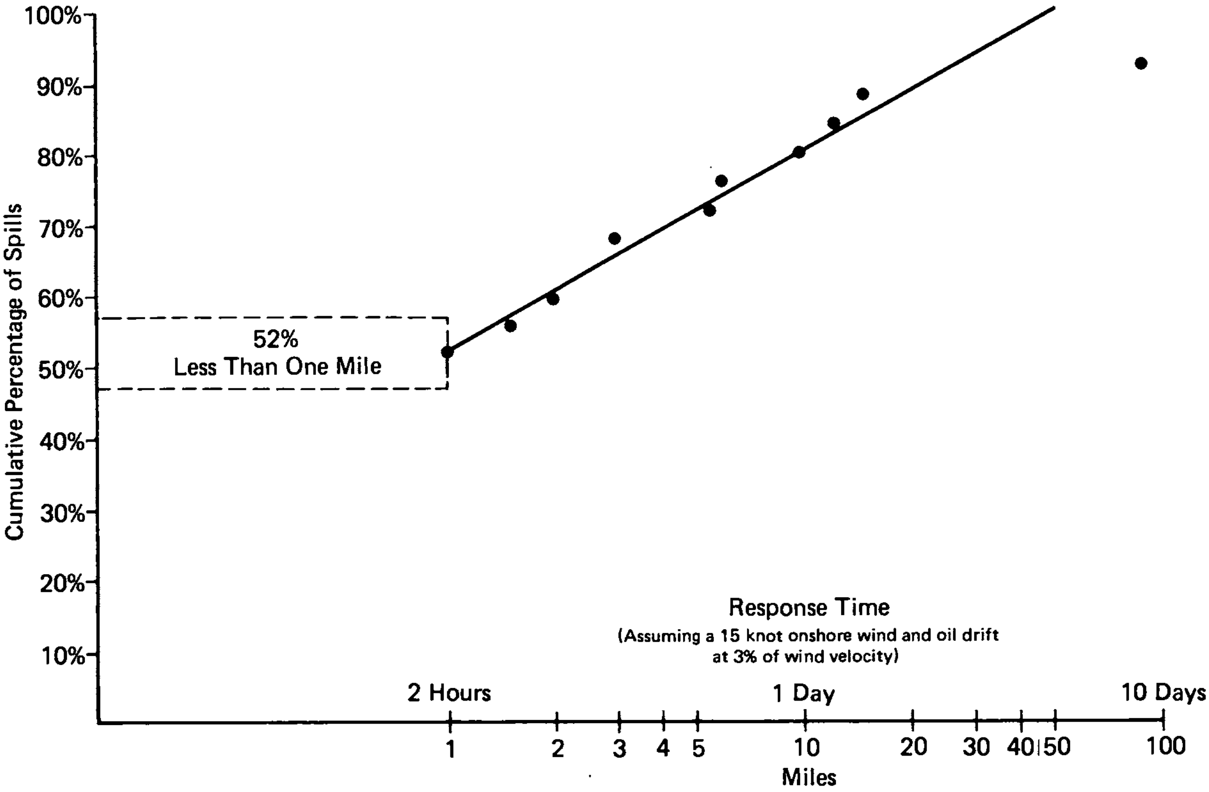

Figure 62. Distance from Shore and Response Time Available for Shoreline Protection (Data from 25 Incidents).

would drift at approximately one-half knot. Thus, with 50 percent of the spills less than 1 mile from shore, an onshore wind could move oil onto the shore in 2 hours, and in 80 percent of the incidents oil could reach the shore in less than a day.

An examination of 21 past spill incidents reveals that the median duration of the incident was approximately 17 days and that 50 percent of these past spills lasted from 5 to 50 days (Figure 63). These data are not at all definitive in that the reported duration of an oil-spill incident will vary greatly depending on the point of view or basis for evaluation of the reporter. The data indicate, however, that logistic support is likely to be required over a period of several weeks in any future major spill incident.

Although the data on extent of coastal contamination were not as well recorded as most of the other characteristics, an analysis of 18 past spills indicates that in 50 percent of the incidents less than 7 miles of coastline were contaminated and in 80 percent of the incidents less than 20 miles (Figure 64). The median value for all of the incidents is 3 to 4 miles of coastline. This suggests that the coastal contamination likely to be experienced in a major spill generally will be less than 20 miles.

Information on utilization of coastline affected by an oil spill is somewhat subjective. There is a tendency to class as recreational any shoreline which is accessible to the public. An analysis of 23 past oil-spill reports indicates that in 85 percent of the spills, recreational coastline was affected, and residential and industrial coastline were each affected in 45 percent of the spills (Figure 65). The total is more than 100 percent since most incidents reported shorelines with multiple uses.

Combining this analysis with the distance of the spill from shore indicates a likelihood that in the event of a spill, shoreline classed as recreational may be contaminated within a day.

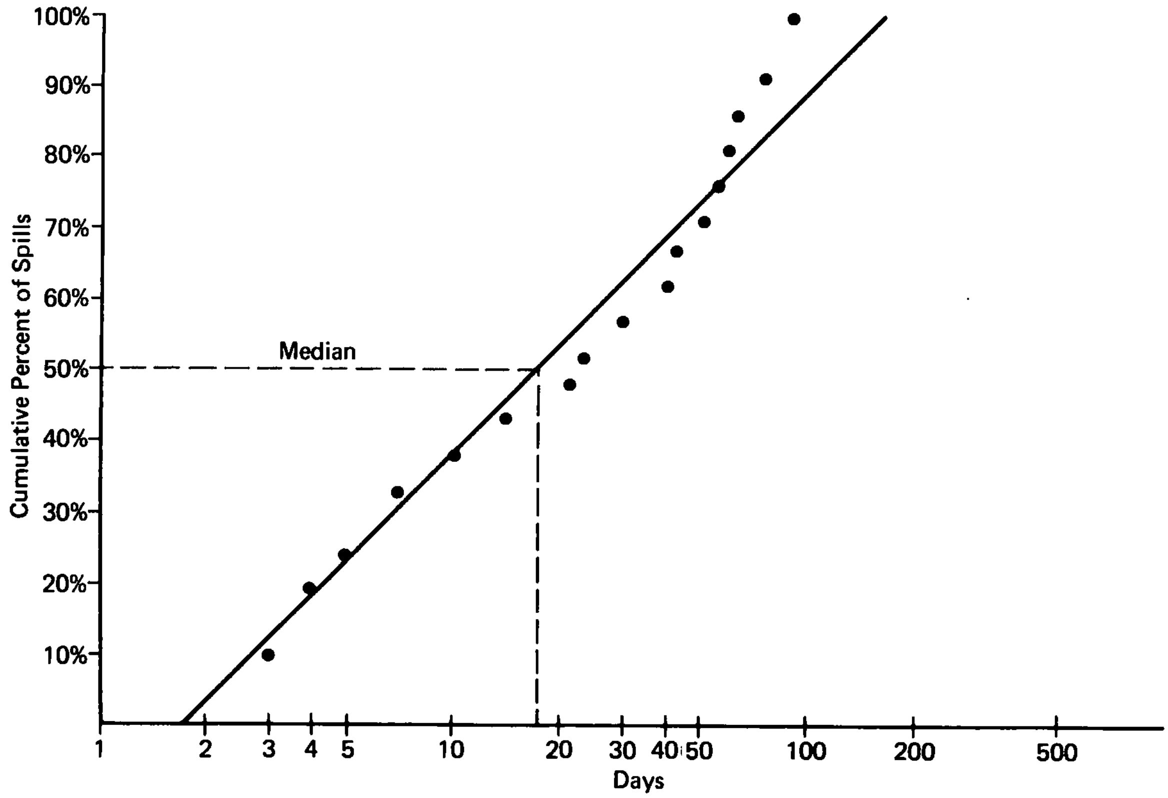

Figure 63. Duration of Spill Incident (Data from 21 Incidents).

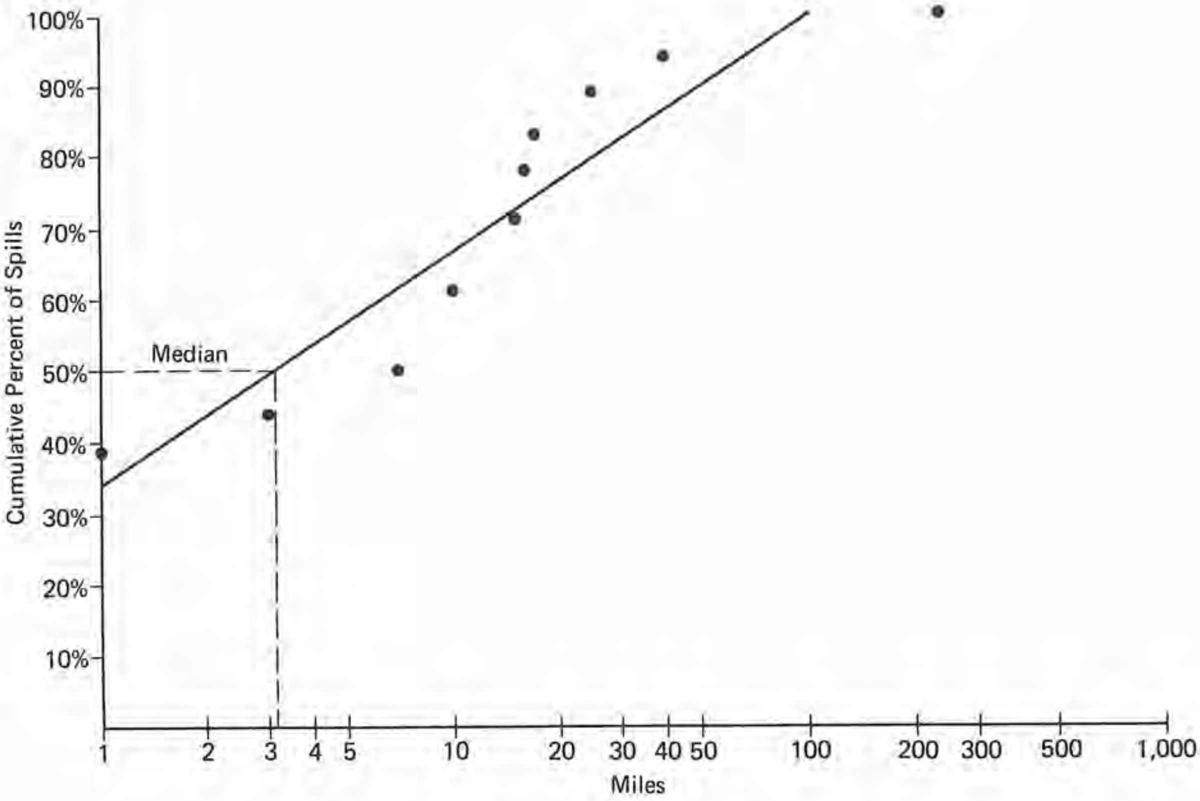

Figure 64. Extent of Coastal Contamination (Data from 18 Incidents).

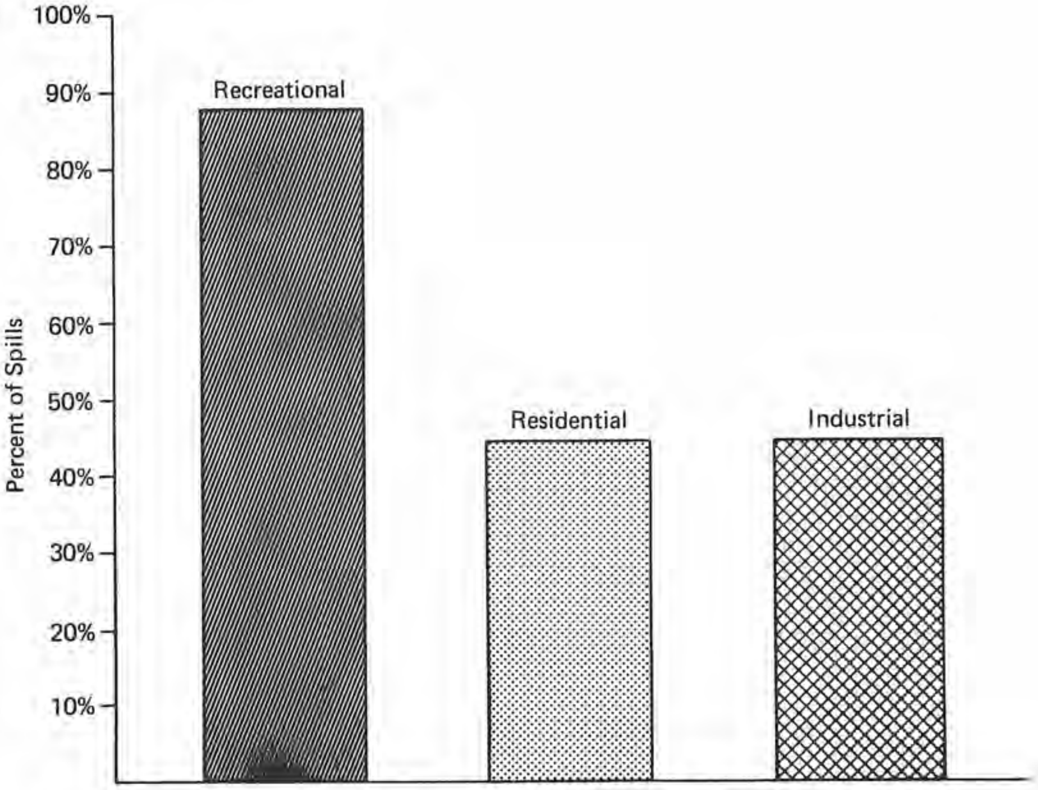

Figure 65. Coastline Utilization (Data from 23 Incidents).

Finally, the distance of the spill from the nearest port is quite significant in planning action to control the spill and the logistic support arrangements required. The analysis of past spills shows that, in general, 75 percent were located within 25 miles of a port and 85 percent were within 50 miles of a port (Figure 66).

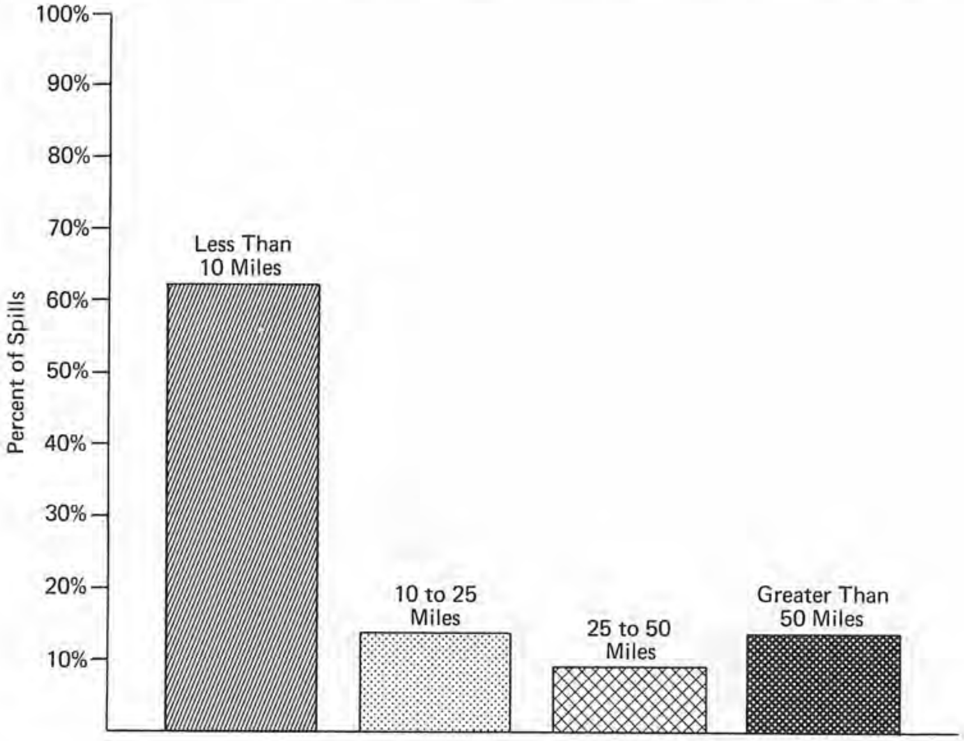

Figure 66. Distance from Nearest Port (Data from 21 Incidents).

In planning response to an oil spill in U.S. waters, it would appear reasonable to plan on locating a staging area within 50 miles of the spill site.

The principal patterns of past oil-spill incidents are summarized in Table 32.

Thus, on the basis of the preceding analysis of past spills, the typical situation that will be encountered in a massive offshore spill is that--

- The source of the spill is likely to be a tanker
- Crude or residual fuel oil cargoes are likely to be involved
- The size of the spill will probably be more than 5,000 barrels (with a median size of 25,000 barrels for those past spills on which data were obtained)
- The spill will probably occur within a few miles of shore
- The duration of the spill incident will be more than 5 days, with a median of 17 days' duration for the past spills on which data were obtained
- The shoreline threatened by the spill will be at least partially recreational, with a reasonable chance that only light coastal contamination will occur (there was a median of 4 miles of contaminated coast for the past spills examined)

- It is fairly likely that the spill will occur within 25 miles of a port suitable for staging control action, and more than likely not more than 50 miles from such a port.

TABLE 32

PAST MAJOR OIL SPILLS

Source	75% were associated with vessels
Cargo	90% involved crude or residual oils
Volume	70% of the spills were greater than 5,000 barrels
Distance Offshore	80% occurred within 10 miles of the shoreline
Duration	75% of the spill incidents lasted more than 5 days
Extent	80% contaminated less than 20 miles of coastline
Coastline	85% occurred off shoreline considered to be recreational
Distance from Port	75% were within 25 miles of the nearest port

B. Geographic Regions of Primary Interest

In order to determine which coastal areas should receive primary attention regarding oil-spill control preparedness, Dillingham utilized statistical data for U.S. coastal areas with a high volume of petroleum traffic. The locations of offshore petroleum production and pipelines were also considered, as were the locations of past spills along U.S. coasts.

The results of the analysis of past spills indicate that tankers are the most likely source of future spills, and that crude and residual oils are most likely to be involved in the spill. Therefore, using published data on petroleum volumes,* Dillingham outlined those coastal regions with a large volume of tanker traffic in which large quantities of heavy oils are being transported.

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*The Department of the Army, Corps of Engineers' annual statistical summary, "Waterborne Commerce of the United States," 1967. Ports or harbors considered were those with an annual waterborne tonnage of all commodities in excess of 4 million tons, except for Anchorage, Alaska, which was included because of the past growth rate in tonnage handled and expected future increases.

For purposes of analysis, the major ports and harbors were ranked in four classes according to the annual volume of petroleum products handled; the classes are 400, 200, 100 and 50 million barrels. As shown in Table 33 and Figure 67, there are only three ports in the 400-million-barrel category: the Port of New York; Delaware Bay; and Beaumont-Port Arthur, Texas. Five ports are in (or close to) the 200-million-barrel class: Portland, Maine; the Mississippi Delta region; Galveston Bay; the Los Angeles-Long Beach Harbor area; and San Francisco Bay. The 100-million-barrel class includes another 5 ports: Boston, Chesapeake Bay, Lake Charles, Corpus Christi and Puget Sound.

TABLE 33

U.S. PORT AREAS HANDLING MORE THAN 75 MILLION BARRELS OF PETROLEUM PRODUCTS IN 1967
(In Thousands of Barrels)

Port and Approaches	Total Barrels* of Petroleum Products	Barrels* of Heavy Oil
Four hundred million barrels:		
Port of New York	781,809	438,053
Delaware Bay	458,885	367,458
Beaumont-Port Arthur	413,567	247,835
Two hundred million barrels:		
Galveston Bay	279,958	115,815
Mississippi Delta	248,815	176,295
San Francisco Bay	196,014	99,246
Los Angeles-Long Beach	158,333	87,591
Portland, Maine	157,892	131,712
One hundred million barrels:		
Corpus Christi	149,226	77,014
Boston Harbor	132,300	49,077
Chesapeake Bay	116,865	64,876
Puget Sound	83,419	22,974
Lake Charles	81,830	61,355

* Converted from short tons at the approximate ratio of 7 barrels per short ton.

Although specific figures on traffic through the Florida Straits "Choke Point" were not available, discussion with marine operators indicated that the annual transit volume would be greater than 400 million barrels (see Figure 67).

The offshore drilling and production areas in the Gulf of Mexico and off the coasts of California and Alaska, and the offshore pipeline network adjacent to the Louisiana coast are also shown in Figure 67.

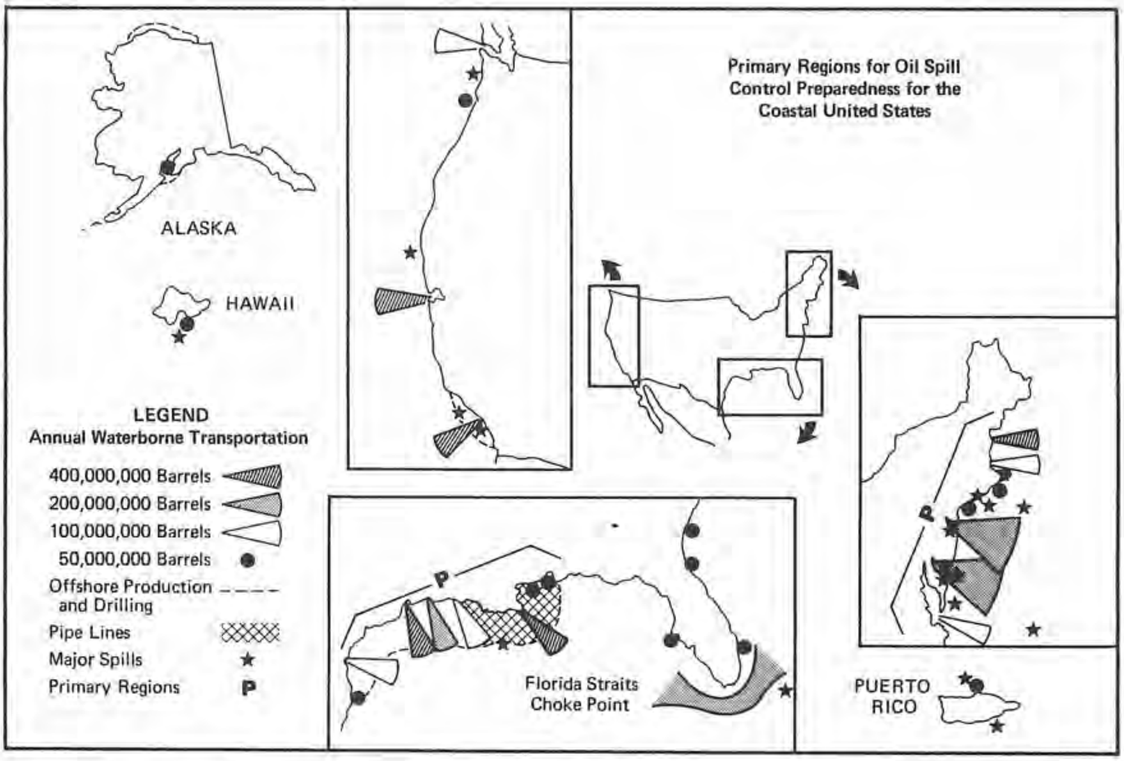

Figure 67. Primary Regions for Oil Spill Control Preparedness for the Coastal United States.

Petroleum traffic through the Panama Canal (not shown in Figure 67) was about 98 million barrels in 1968; thus the Canal is also an important area.

An examination of Figure 67 indicates that there are two broad geographic regions of critical importance: These are the Northeastern regions extending from Portland, Maine, to Hampton Roads, Virginia, where close to 2 billion barrels of petroleum products are handled annually; and the Central and the West Gulf Coast regions from Mobile, Alabama, to Brownsville, Texas, where approximately 1.3 billion barrels are handled annually, and where the most extensive offshore oil fields in the world are located. More restricted areas of major importance include the Florida Straits "Choke Point" (with an annual transit of over 400 million barrels); the three major port areas on the Pacific Coast (Los Angeles-Long Beach, San Francisco and Puget Sound), each handling between 80 and 200 million barrels; and the Panama Canal Zone with approximately 100 million barrels. The offshore production areas in southern California are included within the Los Angeles-Long Beach area.

The location of 19 major spills in U.S. waters are shown in Figure 67. (See Table 34 for the location of all the spills in or near U.S. waters that were examined during the study.) Comparison of the location of these 19 spills with the areas designated as of critical or major importance shows that 15 of the 19 spills, or more than 75 percent, were in or near the areas designated. This close relationship tends to reinforce the rationale used in selecting areas likely to experience future spills.

C. Environmental Factors Affecting Control

In examining the environmental characteristics associated with a major oil spill in coastal waters, an analysis was made of those phenomena which influence the behavior of the oil, the effect of which should be known in preparing to control the oil spill.

TABLE 34

LOCATION OF MAJOR OIL SPILLS IN OR NEAR U.S. WATERS
(From the Period 1956-1969)

1. Buzzards Bay, Massachusetts--*Algol*
2. Narraganset Bay, Rhode Island--*P. W. Thirtle*
3. 120 miles southeast of Nantucket--*Keo*
4. Waterford Beach, Connecticut--drifting slick
5. Arthur Kill, New Jersey--Seewarren, storage tank
6. Delaware River, Pennsylvania--*Kenai Peninsula*
7. Delaware River, Pennsylvania--*Tim*
8. Delaware River, Pennsylvania--New Castle, power station
9. Rehoboth Beach, Maryland--*Hess Hustler*
10. 270 miles east of Cape Hatteras--*Pegasos*
11. Eleuthera Island, Bahamas--*Colocotronis*
12. San Juan Harbor, Puerto Rico--*Ocean Eagle*
13. Guayanilla Harbor, Puerto Rico--*Argea Prima*
14. Ship Shoal, Louisiana--drilling rig
15. Los Angeles Harbor, California--*Martita*
16. Santa Barbara Channel, California--drilling platform
17. Humboldt Bay, California--Eureka, refinery
18. Olympic Peninsula, Washington--*Seagate*
19. Waikiki Beach, Hawaii--drifting slick
20. Los Minos Bay, Canal Zone--*Witwater*
21. Wake Island--*R. C. Stoner*

1. Factors Affecting Floating Oil

The factors which appear to be most significant with regard to their effect on floating oil and possible constraints on control activities are (1) sea conditions, (2) wind velocity and direction, (3) surface currents, (4) tides, (5) water temperature, and (6) atmospheric conditions in the vicinity of the spill. The following paragraphs provide a brief discussion of each of these factors.

a) Sea Conditions

Sea conditions are generally described in terms of wave height, period and direction, as well as swell height and direction. Wave height and period are the most critical factors affecting attempts to contain and recover oil spilled at sea. Short, choppy seas with average wave heights of 1 to 2 feet and average periods of 1 to 3 seconds appear to render most containment booms ineffective because of their inability to follow the wave profile. With longer periods such as occur with long swells, oil containment by a boom appears to be possible in heights up to 2 feet. In waves above 2 feet, most booms and recovery devices appear to become ineffective and many booms experience structural problems, separating at end connections or suffering other failures.

As waves increase in height to an average above 6 feet, the ability of smaller vessels to operate effectively in implementing oil-spill control action decreases significantly. On the other hand, as wave height increases, the natural action of the waves in dispersing the oil through agitation becomes more effective, as does the scouring action of waves on the shore. Thus, unfavorable sea conditions tend to clean up the oil naturally.

Data on actual sea conditions which existed at the time of the initial spill were obtained for less than half of the spill incidents examined. The relationship of wave heights to number of spills is illustrated in Figure 68. On the basis of these data, median wave height at the time of the spill for the 11 spills examined was 5 to 8 feet. Because sea conditions were variable during the course of each incident, the median wave-height figure is not a precise measure. Nevertheless, it indicates (1) that little effective control action would have been possible from smaller vessels at the time of the spill in 50 percent of the incidents because of wave heights above 6 feet, and (2) that containment booms or oil-recovery devices would probably not have been useful in 70 percent of the incidents because of wave heights above 3 feet.

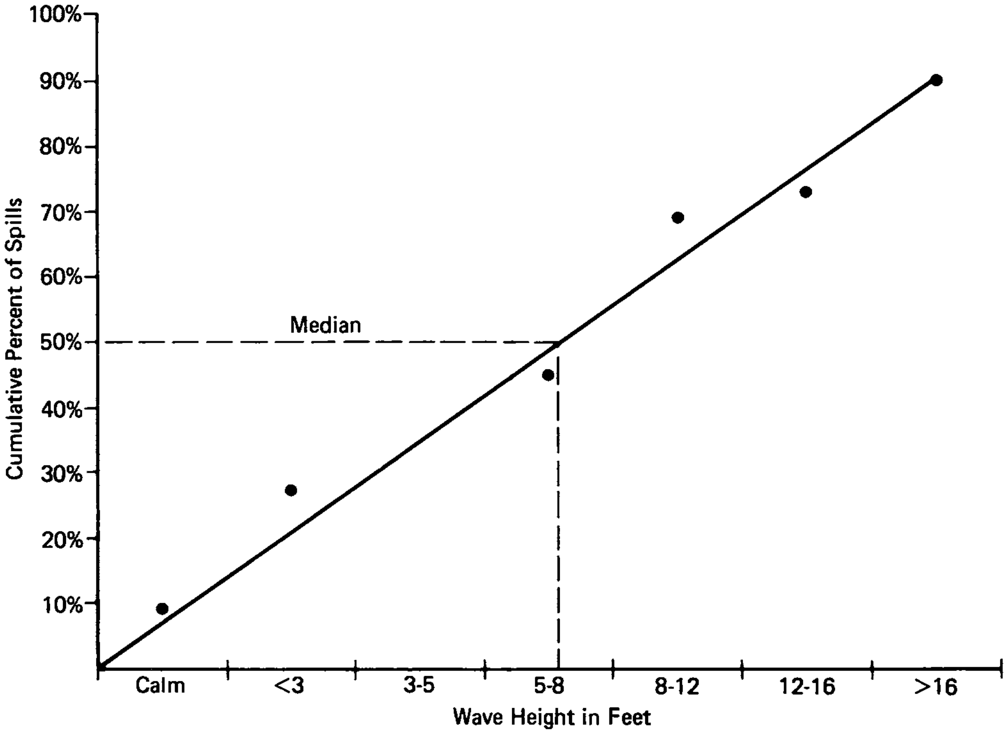

Figure 68. Wave Height at Time of Spill (Data from 11 Incidents).

b) Wind Velocity and Direction

Wind velocity and direction are the most significant factors regarding the movement of oil spilled in open water. Secondary effects of wind are the generation of waves and the promotion of weathering in the spilled oil through evaporation of the lighter fractions.

Observations of oil slicks on water indicate quite reliably an average drift rate at approximately 3.3 percent of the wind velocity in approximately the direction of the wind. Taking account of this will permit prediction of oil-slick movement wherever local wind data are available--this will reduce the need for constant surveillance of the slick.

With oil-slick movement dependent upon the local wind, a reliable forecast of the wind becomes an important aspect of oil-spill control, and the wind direction should always be considered in planning control action. A strong onshore wind may mean that oil will be ashore in a matter of hours when the spill is near the coast. On the other hand, if a shift to offshore winds is predicted, increased efforts to keep the oil temporarily off the beach may be rewarded by a seaward drift of the threatening oil slick with the wind change. Preparations for coastal protection may be assisted by using wind data to predict the approximate location at which a drifting oil slick is likely to come ashore.

On a regional basis, the general coastal wind pattern for the United States is consistent throughout most of the year. Onshore winds prevail along the Pacific Coast for most of the year, whereas in the Gulf of Mexico and along the Atlantic Coast, offshore winds may be expected to occur seasonally.

In the examination of past major oil spills, wind-velocity data at the time of the initial incident were obtained for approximately half of the spill incidents. As shown from the plot of this information presented in Figure 69, the median wind velocity was 17 to 27 knots for the 15 incidents. A wind of this velocity would produce an oil-slick drift velocity of approximately 0.7 knots; and if this wind were directly onshore, oil might be driven ashore in 10 hours from a spill site 7 nautical miles off the coast.

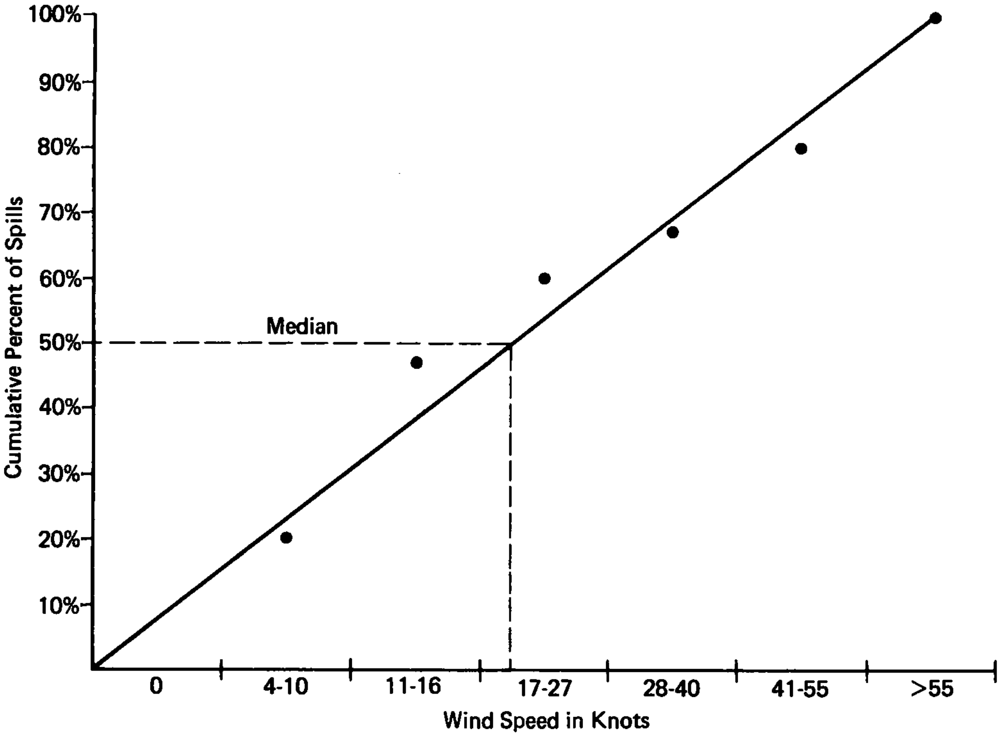

Figure 69. Wind Velocity at Time of Spill (Data from 15 Incidents).

c) Surface Currents

Surface currents in the vicinity of an oil spill may be related to local wind conditions, corresponding to the direction and duration of the wind, or may be prevailing surface currents of a more permanent nature. Nearshore ocean-surface currents are dominated by the effects of tides, which tend to be cyclical, and by winds. Drifting oil will tend to be set in the direction and with the velocity of these surface currents. Where surface currents are solely wind-induced, the previous estimate of 3.3 percent of the wind velocity in the direction of the wind will account for the oil movement. Where other surface currents are present and known, however, their influence on the movement of an oil slick should be considered by geometrically adding the speed and velocity of such currents to the wind-induced drift of the slick in order to predict slick movement.

The presence of surface currents will affect the performance of containment devices used in oil-spill control. A current being deflected under a floating boom will establish flow patterns which will tend to pull floating oil under the boom at fairly low current velocities as the oil drifts against the boom and begins to build up in thickness. Indications are that oil will escape under a barrier at current velocities of less than 1 knot and that increasing the depth or skirt of the barrier will not alter this situation. Surface currents also place additional structural loads on floating booms through drag forces which tend to deflect the boom or boom skirt away from the vertical in the direction of the current. Consideration of these relationships indicates that successful containment of floating oil is unlikely where surface currents of 1 knot or better are setting the oil against a floating boom or fence, or conversely, where the boom is being moved through the water toward the oil at this speed.

d) Tides

The effects of tides, in addition to generating tidal currents, may significantly complicate shoreline protection and cleanup where large tidal ranges are experienced. Efforts to protect the shoreline must be deployed seaward of the low-tide line, and where moored floating barriers are utilized, mooring arrangements must be set to accommodate the rise and fall of tides. If oil is washed onto a beach, changing tides will distribute oil over a band on the beach marked by the high- and low-water lines. This situation may be exaggerated by monthly spring tides or by storm-driven high tides, and a small increase in the tidal range may result in a large increase in the shore area to be cleaned. For the coastal United States, the northeast Atlantic Coast is the only area where tides of significant range are experienced regularly.

e) Water Temperature

The temperature of the surface water will affect the behavior of floating oil and the methods utilized to control the oil. Low temperatures increase the viscosity of the oil, slow the evaporation rate of the lighter fractions and decrease bacterial degradation activity, thus increasing the tendency of the heavier fractions to persist. Where burning the oil is to be attempted, low temperatures will inhibit ignition. The water temperature is a pronounced factor in the effectiveness of chemical dispersants, and temperatures above 60 degrees Fahrenheit appear to be necessary for successful use of dispersants. Consideration must be given to the ambient surface temperatures to be expected in a region while planning preparation for oil-spill control.

f) Atmospheric Conditions

The general atmospheric conditions in the vicinity of an oil spill will influence control activity but will have little effect on the behavior of the oil itself. Low air temperatures will affect the oil in the same manner as low water temperatures and will hamper control activities where hand labor is required. Poor visibility because of fog, rain or snow may have the most significant effect, by restricting vessel operations and by limiting observation of drifting oil slicks. The effects of local storms are felt in the resulting winds and waves (discussed earlier).

2. Coastal Characteristics

A summary of significant environmental characteristics along the coasts of the United States is presented in Figure 70. The wave and wind information included is based on data from the Oceanographic Atlases for sea areas adjacent to these coasts and reflects more severe conditions than will be found inshore, with the exception of the Mid-Atlantic Coast which is from a station located well inshore.

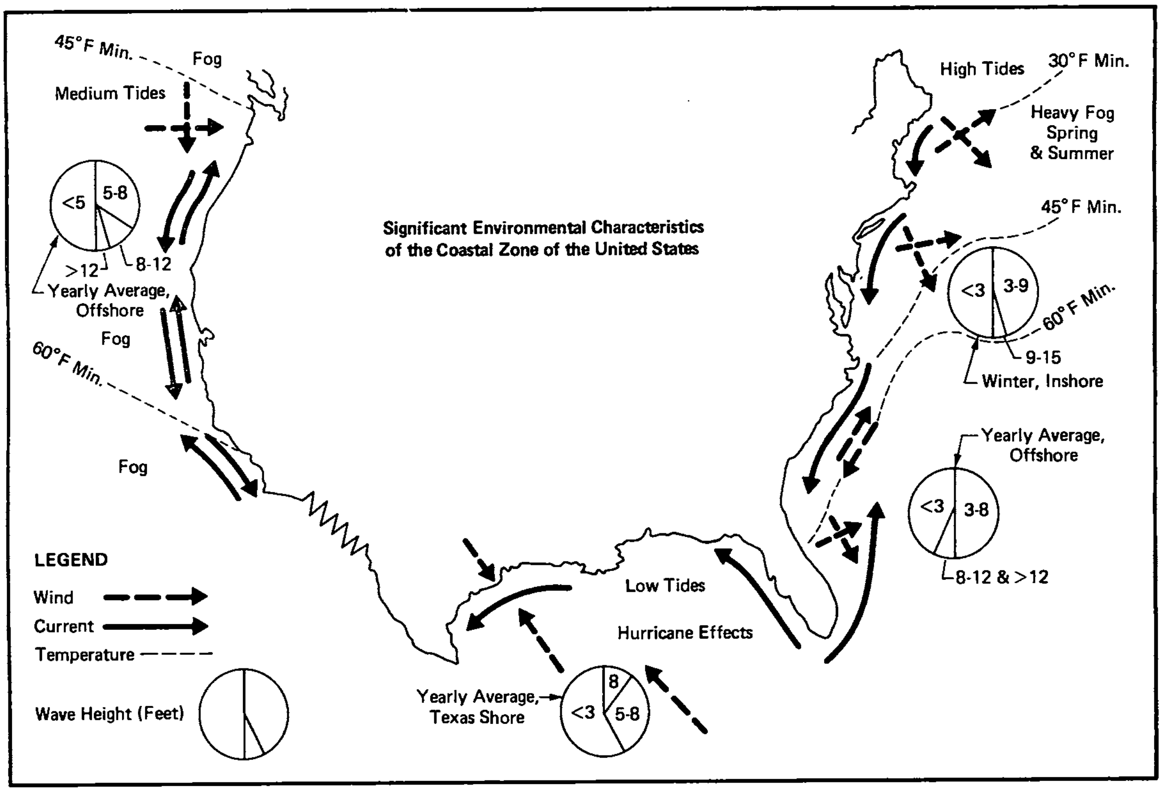

Figure 70. Significant Environmental Characteristics of the Coastal Zone of the United States.

For the middle Atlantic area, wave data are for the winter months, December through February, providing a view of the roughest season. During these winter months, waves of less than 3 feet are experienced 50 percent of the time; waves 3 to 9 feet in height, 40 percent of the time; and waves 9 to 15 feet, 10 percent of the time.

In the Gulf of Mexico for the area south of Houston-Galveston, the pattern is one of decreased wave heights and a short wave period which is highly dependent on the time of year. On an overall yearly basis, wave heights here are less than 3 feet for 55 percent of the time, with 5- to 8-foot heights occurring 30 percent of the time, and greater than 8 feet for the remaining 20 percent of the time. High waves are infrequent except at the time of hurricanes. Local offshore winds from the north in the winter usually flatten prevailing southeast seas.

On the Pacific Coast, the waves and typical long swells tend to shift statistics of wave heights toward higher waves with medium to long wave periods. For the northwest coasts of California and Oregon, the worst conditions indicate that wave heights of less than 5 feet occur 50 percent of the time, 5- to 8-foot waves for 25 percent of the time, and 8- to 12-foot heights for the remaining 25 percent of the time.

In addition to the above generalizations on wave conditions, some general statements are possible regarding wind direction and velocity. Records indicate that offshore winds may be expected about 75 percent of the year along a great part of the eastern United States coast, which would tend to keep drifting oil off the shoreline. Yet, during September and October a relatively high occurrence of northeasterly winds and some southerlies would make much of the East Coast vulnerable. Along the Pacific Coast, records indicate prevailing onshore winds for a majority of the year, providing a great likelihood that any oil spilled near shore will be blown onto the coast. Considering wind velocities, it is reasonable to expect winds of up to 15 knots for 50 percent of the time along the middle and northeastern Atlantic Coast, winds of up to 12 knots 55 percent of the time in the northwestern Gulf of Mexico, and winds of 15 knots 60 percent of the time along the Pacific Coast.

Some average values of environmental characteristics significant in oil-spill control in U.S. coastal waters are presented in Table 35. These average values (and the environmental patterns shown in Figure 70) represent broad generalizations and are intended for long-term regional planning and not as a guide for actual operations on a specific spill. Much more detailed environmental information should be compiled in order to do detailed planning for oil-spill control action for a given response region. Further, highly specific local weather observation and forecasts would be essential in carrying out the control operations on a given spill.

TABLE 35

AVERAGE ENVIRONMENTAL CHARACTERISTICS OF U.S. COASTAL WATERS SIGNIFICANT TO OIL SPILL CONTROL

Coastline	Wave Height (time--feet)	Wave Period (time--seconds)	Onshore Winds (% of time)	Minimum Air Temperature (degrees F)	Tidal Range (feet)	Visibility less than 1 mile (% of time)
Atlantic						
NE	50%>3 ft.	70% 5-7	20%	30°-40°F	9-20	20% spring and summer
SE	60%>3 ft.	---	30%	50°-70°F	2- 4	---
Gulf of Mexico						
NW	45%>3 ft.	75% 4-6	50%	52°-60°F	2- 3	---
NE	---	---	20%	55°-60°F	---	---
Pacific	50%>5 ft.	60% 8-12	70%	47°-60°F	4-10	10% summer and fall

Section 2.
OIL-SPILL CONTROL MEASURES

The goals of oil-spill control are both ecological and economical. The primary ecological goal is the protection of the ecology of the land-water area against permanent harm. The economic goals are protection of beaches, shorelines and associated structures against damage, and the recovery, if possible, of a valuable natural resource--petroleum. To accomplish this task, around-the-clock capability must exist.

A. Containment and Recovery

Oil spills may be contained and often recovered either by purely mechanical methods or by absorption of the oil and subsequent removal.

1. Mechanical Methods

Next to prevention, the most important procedure for mitigating ecological and economical loss from spilled oil is mechanical containment and recovery. Equipment and procedures for containing and recovering oil spills in protected waters are well-developed. Open sea capability is limited. Containment devices that will restrict the movement of oil in the open sea are not available. There have been no demonstrations of oil-recovery devices with the ability to pick up oil from large spills in rough waters at the needed rates and efficiencies.

Spilled oil can be contained by floating booms constructed to prevent the oil from carrying under or slopping over. A typical boom has a flotation system either integral to or separate from the containment portion. That is, the "fence" may be self-supporting by being inflated or filled with some buoyant material, or it may be supported by floats attached externally. Oil is prevented from carrying under by skirts of selected length, weighted in some fashion to keep the boom upright. Chains, sandbags or bar weights have been used. Booms are used primarily to contain oil by encirclement, sweeping oil to a collection point, and/or directing oil by forming a barrier along which the slick moves to a collection point.

Currently available booms are ineffective for containing oil except in protected harbors and calm inland waters. However, for such service, they are easily positioned and are effective. Sweeping speeds must be very slow when booms are used for sweeping. Booms can be used with some effectiveness in directing oil slicks to a given point, provided there is a small angle between the boom and current direction, preferably so that the current normal to the boom is less than one knot.

The usual failure of most booms is that as oil accumulates, it is carried under the boom by the water currents. Lengthening of the skirts requires increasing the strength of boom in order to overcome the hydraulic forces. This requirement results in a massive structure lacking mobility, flexibility and maneuverability.

In addition to the containment problem, open-sea tending and anchoring of booms are difficult. Forces built up by wind and wave action drag anchors and break lines and anchor fittings. Articulated booms are necessary to conform to the surface of the sea; otherwise, when rigid booms ride the wave crest, oil carries through in the wave troughs.

There is a need for containment devices which will function efficiently in heavy seas to prevent the spreading of oil.

It has been proposed that if water depths make anchoring feasible, a breakwater can be installed by anchoring a number of barges end to end, at right angles to the currents and wind. An area of calm water results on the leeward side of the barges in which ordinary booms can collect oil which carries under the barges. Oil trapped on the windward side can be skimmed with available equipment.

Air barriers have been used in harbors at oil-tanker terminals. An air barrier consists of a pipe of some suitable material positioned several feet below the water surface, in some cases on the bottom, from which air is jetted through nozzles along the length of the pipe. The upwelling produced by the stream of air produces a gradient on the water surface which tends to repel floating material. To be successful the air barriers must be tailored for each installation and have not found application in offshore operations because of the variable conditions and forces that occur.

A unique system for containment of ocean-floor seeps has been successfully used. Underwater hoods or tents have been installed on the ocean floor to collect the seep oil and carry it through flexible piping to a suitable container on the ocean surface or structure. The tent center is held aloft off the ocean bottom with buoys, allowing the oil-gas mixture to migrate toward the tent apex to which the transfer hose is connected. The tent is securely lashed to a frame slightly larger than the tent's base dimension. The frame is made from piping, suitably valved for water flooding or air displacement and, hence, serves both as an anchor or flotation system, as needed.

Mechanical devices for recovering floating oil fall into three classifications:

1. Oil-adhesion devices by which the oil is skimmed clear of the water by a rotating drum and then squeezed or scraped from the collecting surface
2. An open-skimmer pipe over which oil and water are skimmed and then pumped to a chamber for settling
3. A floating-surface skimmer with sump from which oil and water are pumped.

The first type of system (oil-adhesion devices) is adequate for small spills in protected waters, but lacks seaworthiness and a recovery rate adequate for large open-sea spills.

The second type (open-skimmer) requires high pumping rates with substantial settling capacity because of the high ratio of water to oil pumped.

The third type (floating-surface skimmer) has performed in relatively rough seas under static conditions where relatively thick (2+ inches) oil slicks occur. Otherwise, small oil quantities are recovered for the gross quantity of liquid pumped.

None of these systems satisfies the needs for recovery of large oil spills.

2. Use of Sorbent Material

Next to containment and mechanical recovery, the sorption of oil and subsequent removal of sorbent from the water surface provides the most desirable method of oil-spill control.

Sorbents may be roughly categorized as (1) natural and (2) manufactured material. Natural substances can be subdivided into treated and untreated material. Treated materials are those naturally occurring clays and fibers which have been conditioned with such things as stearates or amines to enhance their hydrophilic property.

The principal problems in the use of sorbents are (1) obtaining adequate contact with the oil and (2) the recovery and disposal of the material. Wind is a factor in spreading sorbents because of their low density. Windborne particles, in addition to not contacting the oil, can foul air-intake systems on engines and add to the discomfort of workmen carrying out the operation. Dry distribution of the small particle or very light sorbents such as the talc and clays is very difficult if there is any wind. Application can be made by using a water slurry of the material.

In all cases, the key elements are distribution of the material to the slick, adequate contacting of the oil mass, and subsequent recovery of the mixture. No matter how high the oil-sorption properties of any material are, it is of little value if there are no practical distribution and recovery methods available.

Recovery of sorbents on a large scale in open waters may be possible through the use of commercial fish purse seiners, outfitted with properly sized nets. However, equipment must be developed for recovery and removal in heavy seas of both oil and oil-soaked sorbents. On a smaller scale in quiet, sheltered water, aquatic weed harvesting machines may be used. Otherwise, recovery is by relatively inefficient manual collection, using hand tools and open drums.

Generally speaking, sorption with either natural or synthetic materials presents logistical problems of both dispersal and collection which are not adequately met with present equipment.

Disposal of oil-soaked mixture can be by incineration or landfill. In either case, air and groundwater pollution factors may be limiting. Recycling of the sorbent after removal of the oil has been proposed, but except for the rotating drum and belt systems with their capacity and sturdiness limitations, no practical system has been developed.

B. Treatment

While containment and recovery of spilled oil provides the most positive control, the employment of such measures is not always possible. Nature itself has some capacity for disposing of hydrocarbons, and man can hasten the process.

1. Natural Processes

There is substantial evidence that many microorganisms in both saline and fresh waters have great capacity to degrade hydrocarbons. The hydrocarbons are a source of energy for the organisms and are metabolized into a new cell mass. All things being equal, the best treatment of an oil spill would be the natural dispersion by winds, waves and currents, and microbial degradation. Unfortunately, overriding beneficial uses, both aesthetic and utilitarian, preclude this natural treatment except when prevailing winds and currents carry the oil away from shorelines and areas of habitation, recreation and commerce. Oil which is sunk is also known to be converted biologically by bottom-occurring organisms, although in deep water the necessary nutrients, such as nitrogen and phosphorous compounds, may be inadequate for bacterial proliferation.

Where continuous oil slicks prevail, re-oxygenation necessary for biological action may be retarded. Ordinarily, water near the surface of open oceans is supersaturated with oxygen because of the action of the waves. The quieting effect of a continuous oil film associated with increased transfer resistance may account for the reported depletion of oxygen beneath oil slicks. However, the presence of sanitary and storm runoff wastes in the reported* system probably supplied the nutrients for complete oxygen depletion by microbial action, since nutrients are generally the limiting requirement in the biological process. Even under ideal conditions of oxygen utilization, only a maximum of about 13,000 pounds of oil per square mile per day could be degraded, far from enough to prevent a slick from reaching shore if the spill is within the average distance of the shoreline. Biological conversion of spilled oil could possibly be accelerated by addition of nutrients and agitation, but time is usually too limited, except at considerable distances from the shoreline.

2. Combustion

Destroying oil slicks by combustion has been attempted with little reported success. Generally, ignition in the early periods of an oil spill is not desirable because of danger to both personnel and property. After weathering on the ocean surface, crude-oil volatiles are lost and the slick is thinned, making ignition and continuous burning difficult. To continue burning, enough heat must be generated to keep the oil at its ignition temperature.

In order to burn an oil slick deficient in volatiles and too thin to maintain combustion, the use of a wicking material containing a combustion promoter has been suggested. There have been reported successes of some such devices but none on a large-scale spill. The possibility of sustaining burning to completion by wick action of materials spread on a sea slick should not be overlooked, but the very definite dangers and uncertainties must be carefully evaluated before such a process is attempted on a major spill.

In summary, burning of spilled oil in the open ocean, allowing for limitations for safety and property protection, has not yet been developed to a practical point.

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*Unpublished observations at Santa Barbara.

3. Sinking

Materials for sinking oil have been available for many years, but their use has never been widely accepted because of objections by regulating agencies responsible for fish and game. There is widespread concern that sinking merely transfers a pollution problem from the water surface to the bottom environment, where it may seriously affect sea-bottom life.

The chemical and physical processes involved in sinking oil are not clear. In one method of sinking, by which use is made of the additive density of the sinking agent in combination with the oil, it is presumed that the sinking-agent particles are hydrophobic and will retain the oil indefinitely. The French claimed a major victory in the *Torrey Canyon* episode by sinking an estimated 20,000 tons of oil with 3,000 tons of stearate-treated chalk and there have been no reports of resurfacing oil. However, this oil had been extremely weathered and was probably so appreciably emulsified that it needed but little additional density to cause sinking.

Another proposed method utilizes the sinking agent to absorb the oil, especially fresh, low-viscosity oil. The sinking agent is sprayed on the slicks in a steady stream, and as the particles travel through the slick, they absorb oil in layers. The relatively high density of the absorbent compared to the oil carries it to the bottom. However, the ratio of oil to sinking agent is probably very small.

A solution to the logistics problems of sinking agents and cost-effectiveness is under study by one petroleum company, which is looking into the possibility of dredging large quantities of sand from the sea bottom or nearby sandbars and of making the wet sand oleophilic by treating it, while on board the dredge, with an organic amine. The dredge is equipped with spray booms which spread the treated sand over a wide path as a wet slurry and provide adequate force to mix the sand and oil. If the method is effective and it can be shown that the oil-sand mixture is not harmful to benthic organisms, it will be a valuable tool in controlling oil spills.

Many other sinking agents have been tried, but to date there are no adequate data to reliably evaluate their oil-removal capabilities. Oleophilic particles, as expected, are better sinking agents than hydrophilic agents. Surface area per unit weight is important. The method of application and degree of mixing and other operational parameters affect the rate and degree of oil removal.

There are very serious questions about the ecological consequences of sunken oil. Most ecologists agree that it is undesirable in shellfish-producing and intertidal areas. In deep water, the ecological effects are not clearly demonstrated. There is good evidence that biological degradation may negate any lasting deleterious effects but may also promote resurfacing of the oils by degrading the oleophilic agents.

4. Dispersants

Chemical dispersants have been widely used material to control past oil spills. Such use of chemical dispersants is now controlled by EPA in the waters of the United States. As there are a large number of effective products available, and their method of application is relatively simple, the use of such dispersants has become one of the more versatile and serviceable spill-control methods.

The dispersants presently available may be broadly classified as water based or organic solvent based. As a general rule, the solvent-based dispersants are effective over a wider range of conditions and petroleum products. They tend, however, to exhibit greater toxicity characteristics and generally to have lower flash-points, and thus require somewhat greater care in handling and application than their water-based counterparts.

The dispersants generally are applied by spray equipment, followed by agitation to mix the chemical with the oil to obtain maximum effectiveness. If the chemicals are properly applied, the floating oil will be dispersed throughout the upper layers of water in finely divided drops and will not reform into continuous slicks. In this form the surface area of the oil is greatly enlarged, resulting in a substantial increase in the natural rate of oxidation and biodegradation of the oil.

The effectiveness of the majority of dispersants is severely limited by low oil temperatures resulting from either cold water or cold air. They are most effective on light oils or freshly spilled oils and become less effective as the oils weather and become more viscous.

The use of dispersants is frequently restricted by government regulations, because of the possibility of toxicity to marine life. The danger of toxicity is considered to be minimal where dispersants are applied in open water or in water of sufficient depth, so that with agitation the chemical is rapidly mixed throughout the upper water column. The primary toxic danger lies in the heavy application of dispersants in enclosed or shallow waters where there is little intermixing with water, with the result that the chemicals are not adequately diluted. With proper application, however, the possible toxic effects of dispersants should not be a significant limitation.

Definition and classification of chemical and natural treating agents for both offshore and onshore use are required to provide safeguards in their use.

C. Contingency Plans and Cooperatives

Members of the petroleum industry have moved forward in the development of contingency plans to control spills of all sizes and from whatever source, and have taken the preliminary steps necessary, within the resources available to them, to put these plans into effect. The basic principles of contingency planning to combat oil spills are the same, whether the spill be large or small. However, the means necessary obviously vary with the size and location of the spill, ranging, for example, from a small spill from a refinery or vessel in inland waters to a major incident at sea.

Late in 1969 API prepared and distributed to the industry a model contingency plan for dealing with oil spills. The plan is essentially a framework which can be utilized in constructing a plan suited to a company's organizational needs. It has four purposes:

- To provide a list of jobs that must be done when oil is spilled
- To provide for the assignment of such jobs
- To provide channels of communication that will ensure coordination of efforts
- To provide reference materials dealing with antipollution measures.

An appendix to the plan includes a list of equipment that can be used in combating a spill.[297]

In addition, API has been urging its member companies to form harbor cooperatives for the pooling of equipment to be available when required if a large oil spill occurs. In early 1970 there were 42 such cooperatives in existence and 35 more under development.

D. Cleanup and Rehabilitation

When all efforts fail to prevent harmful deposition of spilled oil on nature's elements or the works of man, several methods have been tried--and work is going on to develop others--to clean up and to overcome the damage done. The basic problem of cleanup and rehabilitation lies in the vast variety of circumstances which can surround a spill--the nature of the oil spilled, the effects of methods (such as chemical) used to treat the spill, the weather, the condition of the body of water where the spill took place, the nature and state of development of the adjacent land, the nature of the marine life and wildlife in the area--all of these combine to make any single standard solution impractical. Perhaps the best way to illustrate this is to outline the problems faced and solutions tried in cleaning up the coastline affected by the oil spills of the *Torrey Canyon* and at Santa Barbara.

1. Torrey Canyon

Following the *Torrey Canyon* spill (based upon research by the Warren Spring Laboratory, Ministry of Technology), the British Navy had instructions to use detergents in efforts to control and dispose of the oil. These emulsifiers, composed primarily of a petroleum solvent, dilute the oil, and surfactant dissolved in the solvent forms a film around discrete drops of oil.

The British Navy in less than 3 weeks sprayed 700,000 gallons of dispersant on the oil slick at sea and another 1,200,000 gallons were sprayed, dumped and poured on the polluted shores and beaches. The entire operation consumed a total 2,500,000 gallons of detergents and dispersants in sea operations and treatment of affected sections of 140 miles of the Cornish Coast.

Within a week after the *Torrey Canyon* went aground, oil began washing ashore along the beaches and associated coves and cliffs of the Cornish Coast. The bulk of the oil encountered was a water-in-oil emulsion which observers christened "chocolate mousse," which depended largely for its formation upon the nature of the crude and agitation of the ocean.

A description of the variety of deposition on shore was given by L. R. Beynon, who indicated that, in some places, a band of oil had been deposited by the spring tide above the normal high-tide mark and some beaches had layers of oil on or near the surface of the sand or shingle. Others had up to 3 feet of clean sand deposited on top of the oil, and oil was spread over rocks and lying in rock pools.[298]

In the hardest-hit areas, the heavy concentrations of oil and emulsions clearly indicated that simply spraying with detergents and depending on the tides to wash the sands was not enough. As stated in the Report of the Committee of Scientists, "...it was recommended that the top 12-inch layer of heavily contaminated beaches should be pushed by earthmoving equipment to the low-water mark and sprayed with detergent. After the polluted sand and shingle had been washed by the tide, the whole area was to be chain harrowed and treated lightly with further detergent."

There were many volunteers who had no idea of the proper use of the chemicals. Beynon described the scene thusly: "Detergent was being sprayed or slopped from boats close to the coast with little effect and its application to beaches and rocks was, in general, remarkably inefficient and wasteful at this early stage. It included: spraying; dribbling out of hoses fed by gravity or semi-rotary pumps; pumping through hoses; pouring from watering cans and buckets; tipping out of drums; and upending drums from cliff tops." And Beynon adds: "There was often a lack of appreciation that application of detergent without subsequent water washing could be worse than useless."

In some cases deep furrows were dug in the sand and detergent poured without limit into them to await the tide. Heavily deterged areas awaited tides that never reached them. Consequently, the oil and detergent penetrated the beaches up to depths of 5 feet. Where excessive volumes of detergents were used and bulldozers had pushed the treated sand toward the sea, the mixture had been washed back up the beach and retreated again and again until ultimately a treacherous quicksand, saturated with detergent, developed.

It was discouraging experience for hardworking crews whose only shortcoming was a complete lack of knowledge of the sophisticated chemicals they had been told to use.

On the morning of April 10 oil reached the coast of Brittany and continued until April 28. The removal techniques of the French were entirely different from those of the British. The French used no detergents until nearly finished with the cleanup. Near the end of the operation, they used about 500,000 gallons of cleaning agents in order to have clean beaches for summer tourists.

The French physically removed the oil from the beaches. It was almost entirely "chocolate mousse" and quite deep in places. They scooped it into pails and dumped it into sumps dug behind the beaches. The sumps were emptied, using suction trucks, and along with some oil recovered at sea by a skimming device were disposed of by burning.

At the French Maritime Biological Station at Roscoff, students fashioned homemade booms out of straw-filled burlap bags and successfully stopped incoming oil with them. Their success resulted principally because of the calmness of the sea and the relatively small quantity of oil coming in. Booms used in Cornwall tended to break apart in the heavy seas and except in calm harbors failed to contain the oil which slopped over or carried under the barrier.

The French used sawdust and, with greater success, straw to collect oil at sea. Another successful technique involved laying straw or gorse along a beach at low tide. The incoming tide rolled this material up the beach and picked up the oily sand. The straw or gorse was then removed and burned. Scientists from the Plymouth Laboratory, who later visited Brittany, reported: "Repetition of the process over a month was said to be most effective, and the sandy part of the beach at Locquirec, for example, where this method had been used, was clean."

2. Santa Barbara

In the Santa Barbara Channel, pollution control efforts to mitigate pollution of the ocean and seashore were instituted on the day following the oil emission adjacent to Platform A. On that date (January 29, 1969), the U.S. Government authorized use of chemical dispersants to control the oil slick and application of the dispersant was started at once. On February 2 it was decided to attempt to reinforce with straw a natural current barrier or rip line along which storm debris had collected. This rip line extended practically the entire Santa Barbara and Ventura County coastline at varying distances from the shore dependent upon water currents. Chemical dispersing, straw broadcasting and oil skimming were carried on continuously.

A storm on February 4 and 5 broke up the oil slick. Many sections of beaches were oil covered. The major effort then shifted to beach restoration.

The involvement of the beaches with oil presented a new set of problems. Absorption of the oil by some means to prevent penetration into the sand was considered to be of prime importance. Again the straw mulchers were used both from the shore and directly on the beaches to absorb the oil.

Open beaches and the harbors were the areas receiving the first concentrated effort. Later, the rocky areas and seawalls were cleaned. Limited accessibility in some areas slowed the restoration. The tremendous volumes of driftwood and debris deposited on the beaches and coastline greatly retarded the cleanup efforts. It is estimated that over 30,000 tons of storm debris were disposed of.

The beach cleanup was principally by utilizing hand labor for raking up straw. In accessible areas on non-rocky beaches, graders, bulldozers and skip loaders augmented the hand labor. Under these circumstances, 50 men aided with 4 skip loaders, 2 bulldozers and 10 trucks could clean 1 mile of beach per 8-hour day.

Rocky beach, seawall and breakwater cleaning with manual labor, hydroblasters, sandblasters, and steam and warm water was slow, arduous work.

On the beaches, natural clays, treated and untreated, did not materially aid in the oil removal. Straw was effective but when deposited by the tides in rocky crevices was difficult to remove. Burning was unsuccessfully tried for both oil and straw removal. Straw mulchers were very successful for a high rate of straw broadcasting both at sea and on the shore. No good mechanical retrieval system was found or developed. The littoral sand drift is reported to have covered some of the oil-soaked straw.

Rock and seawall cleaning was successful using warm water, steam, hydroblasting and sandblasting. Naphtha-impregnated talc was in some cases used on rock seawalls prior to hydroblasting to absorb the freed oil and prevent recontamination.

The disposal of oil-straw-sand mixtures along with storm debris was difficult. A tremendous quantity of wood, trash, leaves and kelp deposited on the beaches and shores by severe winter storms became oil covered and had to be removed. Up to June 1, 1969, some 9,826 truckloads of oil-soaked straw and debris had been disposed of. Legal disposal sites within a reasonable distance of Santa Barbara could not be located. Santa Barbara city officials denied the use of their dump. The county dump was inaccessible because of a road washout. Ventura and Oxnard dumps were shortly overtaxed. Many loads were hauled to Fillmore, over 50 miles distant. The city and county of Ventura authorized burning of the debris at certain locations, which aided materially in the cleanup.

In addition to the cleanup of the beaches and shoreline, arrangements were made for the cleanup of some 1,000 boats and of private seaside homes and yards which had been fouled by oil during the high tides and windstorm on February 4 and 5.

3. Marine Life and Birds

Marine organisms and wildlife exposed to an oil spill present an entirely different set of problems and solutions.

Crude oil has a variable toxicity to marine organisms, depending on its composition and period of weathering. Toxic materials, if any, are usually concentrated in the more volatile fractions of the crude oil. As the oil is exposed to the elements and to sea water, these lighter materials evaporate, leaving a denser residue on the water. As exposure is prolonged, the chemical oxidation and bacteriological degradation assimilates other parts of the crude oil. Finally, there remains a tarry mass more or less emulsified, depending again on the nature of the residue. Once the volatile fractions have evaporated, the residue is relatively nontoxic to marine life except birds. No matter how long an oil slick has weathered, it is a fatal trap for seabirds, who seem fatalistically attracted to it.

It is possible to limit the impact of an oil spill on seabirds through prompt and correct retrieval and treatment. However, these are not simple procedures and require the supervision of trained personnel. The following summary of some of the requirements is indicative of the care that must be exercised.

a) Retrieval

Waterfowl are most likely to become oil-soaked while some distance offshore. However, upon becoming oiled they tend to go ashore. Consequently, efforts to retrieve birds can be concentrated at or near the shoreline.

The retrieval of birds is best accomplished at low tide. Generally, the birds can be readily caught by hand but a net may be needed to catch the more active ones. Care must be exercised in picking them up and handling them in order to minimize stress. They should be placed in boxes and brought in within an hour, if at all possible, to a cleaning station.

b) Treatment

Upon arrival at the washing station, the bird is carefully treated by following a series of specific steps. The first step is to force-feed it to clear ingested oil from the digestive tract. Lightly oiled birds are satisfactorily washed by immersing in a detergent solution and simultaneously cleaning the inside of the beak of oil coating. A second step must be taken to intensively clean severely oiled areas, followed by repetitive rinsing.

If no one is available who is experienced and knowledgeable in cleaning and rehabilitating birds, obtaining the services of an expert in this field is highly recommended. The duties of this person would be to instruct the workers in cleaning procedure, supervise them, direct the subsequent drying and treatment operations, and make sure that proper records are maintained.

Immediately after the bird has been washed, it should be placed in a dry, roomy area and should be kept in the temperature-controlled facility for at least 12 to 24 hours. If space is available, it should be kept until the third day.

Subsequently the bird should be transferred to a long-term caring facility, located as close to the interim drying facility as possible so as to minimize stress in handling during the transfer.

Most birds, such as ducks, that rely on their natural waxes for waterproofing to keep themselves from drowning, must be kept in these long-term caring facilities until their natural waxes are restored. This may not occur until the bird has gone through a molt, which could be as long as 6 months or a year.

Part III

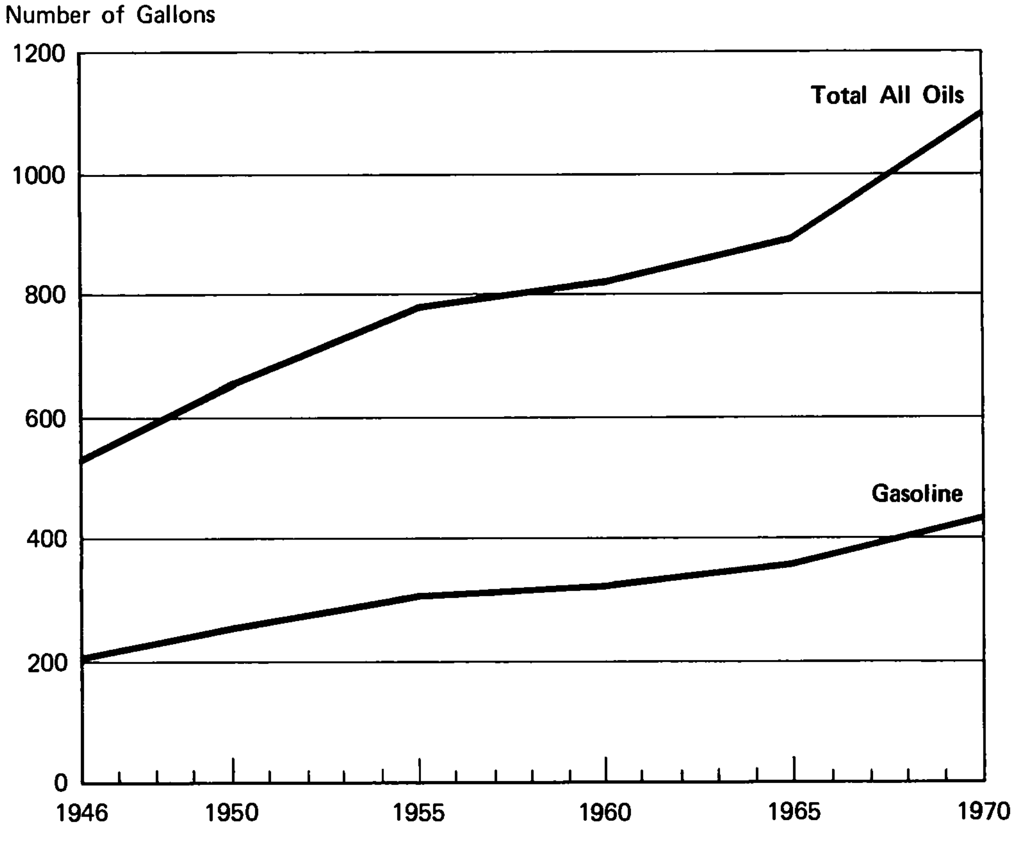
Use of Industry Products

Chapter Eight

THE FUNDAMENTALS OF PRODUCT USE

In the quarter century since the end of World War II, the demand for petroleum products has grown enormously in both size and complexity. In 1970, for example, there were almost 90 million private passenger automobiles in the United States alone, as opposed to 28 million in the first years after the war. Numbers of vehicles alone, however, give only one aspect of the growth. Along with the increase in numbers have come a variety of complex improvements in engine design and in needed petroleum fuels. The expansion has not been confined to the private automobile, however. It has extended to all fields of transportation, heat and power--from farm equipment to jet aircraft, from heating private homes to heating hugh modern office buildings, from industrial use to the generation of electric power. With this increase in demand has come a growing need to control pollution of the air in the concentrated urban areas of today's society.

In 1946, the total demand for petroleum products was less than 5 million barrels per day, compared with the 1970 demand for automobile gasoline alone of almost 5.8 million barrels per day. Total demand in 1970 was almost 15 million barrels per day, which represents a per capita consumption of 1,098 gallons per year, up from 531 gallons per year in 1946, as shown by Figure 71.



Source: Tables 36 and 37.

Figure 71. U.S. Per Capita Demand-Gallons per Year.

By far, the most spectacular growth was in air travel, where aviation fuel consumption increased approximately 30 times over the 1946 level. Increases in major fuel product outputs during the postwar period were as follows:

	MB/D 1946	1960	1970	Average Annual Increases (% per Intervening Year)
Total Gasoline	2.0	---	5.8	4.7
Jet Fuel	---	0.4	1.0	10.0
Distillates	0.7	---	2.5	5.7
Residuals	1.3	---	2.2	2.2

Home heating demand for distillates increased sharply after the war, chiefly because of the postwar popularity of oil over coal heating. Railroad conversion from coal to diesel-powered locomotives also increased distillate demand. Recently there have been sharp increases in the demand for residual fuels for industry and electric power generation.

Asphalt products, both paving and roofing types, have seen rapid growth in their use. New techniques in asphalt-highway construction have been developed to the point where asphalt highways can be built for less money and require less maintenance than comparable concrete highways.

Along with the increase in volumes, the quality of virtually all products has been improved significantly; many of these improvements have not only met the basic need for efficient and economical energy, but have also reduced undesirable emissions into the air.

To cite a few examples, additives now are used in motor gasolines, not only for octane improvement and stability but also for cleaning carburetors, preventing carburetor icing, preventing corrosion, reducing spark plug fouling and for many other quality improvements. Volatility is now varied seasonally and geographically to give the consumer peak performance in quick starting and warmup while minimizing evaporation loss and carburetor icing. Sulfur reduction of distillate products, diesel fuels, heating oil, kerosine and naphthas has greatly improved odor, emissions into the atmosphere, anticorrosiveness and stability of these products. Specialty products (i.e., solvents, naphthas, waxes and LPG) have greatly increased in volume and variety, and, in general, the trend has been toward purer, higher quality products with more exacting specifications.

With respect specifically to product emissions, great progress has been made in the past 25 years. Sulfur has practically been eliminated from gasoline and reduced to very low levels in diesel fuel and No. 2 furnace oil (see Table 41, p. 288), and the average sulfur levels in heavy fuel oils reduced substantially with greater reductions to come. In a few years very little heavy fuel oil of over 1-percent sulfur will be consumed in the United States.

Automotive emissions have been materially reduced since 1960. These emissions consist primarily of hydrocarbons, carbon monoxide, nitrogen oxides and particulates. By virtue of crankcase, exhaust and evaporative-loss controls, the 1971 model automobile has reduced its emissions of hydrocarbons and carbon monoxide by greater than 80 percent over the 1960 model. Industry's gasoline-volatility control by season and locality has tended to reduce evaporative losses, but the new hardware to trap virtually all evaporative losses will be even more efficient.

Progress still remains to be made in the field of automotive-emissions control in order to meet the requirements established for 1975-76 models. Lead alkyl levels in gasoline are being markedly decreased by voluntary action of petroleum companies so that low-/no-lead gasoline should be widely available by 1975, as is indicated on pp. 278-279.

Chapters Eight through Ten are concerned with industry progress and problems in providing an efficient and economical source of energy whose use will be compatible with requirements for atmospheric quality, for today it is the air--rather than the land or water--which is the direct receiver of the emissions from use of petroleum fuels. Significant pollution problems of land or water from use of products (e.g., disposal of used oil) are reviewed in "Industry Operations," Chapters Three through Seven.

While the petroleum industry recognizes that it is an important element in the total environmental conservation picture, it is by no means the sole element, and satisfactory environmental conservation requires a comprehensive approach in which all of society must participate.

Section 1.
PETROLEUM FUELS DEMAND SINCE WORLD WAR II

Petroleum products provide a major part of energy for transportation, a substantial part of the energy for the production of electricity, and the raw materials for many of the products throughout our economy. Petroleum provides the fuel for the mobility required for national security and contributes greatly to national growth and the well-being of the people.

The demand for petroleum in the United States has grown substantially in the postwar period. This rapid growth is summarized for all petroleum products in Table 36. The total oil demand in 1970 approached a staggering 226 billion gallons, more than tripling the 1946 demand of 75 billion gallons. This growth has required an enormous expansion in transportation facilities, since each gallon of gasoline travels an average of about 1,000 miles while en route from the crude field to the refinery and to the ultimate consumer.

The chief factors contributing to this increased demand for oil in the United States have been the population growth, the rise in real per capita income and the rise in industrial production.

In the postwar years, these factors have resulted in large increases in vehicle registrations, air passenger and cargo miles, and in central oil burners for home heating. Salient statistics are given in Table 37.

Since 1946, population has increased from 142 million people to 205 million people or almost 45 percent, equivalent to 1.6 percent per annum--versus annual growth rates in GNP* (constant dollars) of 3.6 percent and FRB† of 4.5 percent. The per capita income in the United States has more than doubled, rising from $1,500 in 1950 to over $3,300 in 1970. This gain in per capita income comes partly from inflation but chiefly from increased production, improved technology, and new capital equipment with the resulting rise in productivity.

Looking at the major oil product, gasoline, we can explain the growth in demand as follows.

After the war, the number of operating automobiles was equivalent to one for every five people, in spite of the fact that car production had been stopped during the war. By 1950, the increase in unit car registrations over 1946 was greater than the gain in the number of people during the same period. As a result, there was one car for every 3.8 people in 1950. By 1965, car registrations grew to the point where there was one car for every 2.6 people and many households had two or more cars. In 1970 the figure had changed to one car for every 2.3 people (see Table 38).

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*Gross National Product--a measure of total goods and services produced by the Nation.

†Federal Reserve Board Index--a measure of the Nation's industrial production.

TABLE 36

U.S. DOMESTIC PETROLEUM PRODUCT DEMAND BY USES
(Thousand Barrels per Day)

	1946	1950	1955	1960	1965	1970	Average Annual Increase (Percent) 1946/70	1960/70
Gasoline								
Automotive	1,920	2,534	3,353	3,845	4,592	5,785	4.7	4.2
Aviation	35	108	192	161	120	54	1.8	(11.5)
Special Naphthas*	60	82	110	124	147	242	6.0	6.9
Total Gasoline	2,015	2,724	3,655	4,130	4,859	6,081	4.7	3.9
Jet Fuels								
Naph-Type	---	---	154	280	271	249	---	(1.2)
Kero-Type	---	---	---	91	333	716	---	22.9
Total Jet Fuels	---	---	154	371	604	965	---	10.0
Intermediates								
Kerosine (ex Jet)	244	323	320	271	267	263	0.3	†
Distillate								
Heating	406	646	978	1,195	1,304	NA‡	---	---
Diesel	148	287	464	563	718	NA	---	---
Other Distillate	111	149	150	114	104	NA	---	---
Total Distillate	665	1,082	1,592	1,872	2,126	2,540	5.7	3.1
Total Intermediates	909	1,405	1,912	2,143	2,393	2,803	4.8	2.7
Residual Oils								
Heating	136	199	236	342	428	NA	---	---
Other Residual	1,179	1,318	1,290	1,186	1,179	NA	---	---
Total Residual Oils	1,315	1,517	1,526	1,528	1,607	2,204	2.2	3.7
Lubricants	96	106	117	117	129	136	1.5	1.5
Asphalt & Road Oil	135	179	254	302	368	447	5.1	4.0
LPG								
Chemical Use	20	41	97	196	343	NA	---	---
Residential & Commercial Use	49	132	183	275	312	NA	---	---
Other LPG	40	61	124	150	186	NA	---	---
Total LPG	109	234	404	621	841	1,016	9.8	5.0
All Other	333	342	438	449	503	1,064§	5.0§	9.0§
TOTAL DOMESTIC DEMAND ALL PETROLEUM PRODUCTS	4,912	6,507	8,460	9,661	11,304	14,716	4.7	4.3
Net Imports∥	(42)	545	881	1,604	2,282	3,159		
Net Imports as Percent of Total Domestic Demand		8.3	10.4	16.6	20.2	21.5		

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* 1965 and 1970 include naphtha 400° for petrochemical use--65 and 157 MB/D, respectively. Earlier years estimates at 3 percent of total gasoline demand.

† Less than 0.1 percent.

‡ Detailed breakdown for 1970 not available.

§ Reflects correction to extract table in Volume I, p. 79.

∥ Total imports less exports.

Source: U.S. Bureau of Mines, *Mineral Industry Surveys* (Monthly and Annual Petroleum Statements; Annual Sales of Fuel Oil & Kerosine; Annual Sales of Liquefied Petroleum Gases).

TABLE 37

FACTORS AFFECTING U.S. PETROLEUM PRODUCT DEMAND

United States	1946	1950	1955	1960	1965	1970
Total Population (000's)	141,936	152,271	165,931	180,864	194,572	205,400
Per Capita Income						
Current $	1,249	1,496	1,876	2,215	2,746	3,334
Constant 1958 $	---	1,810	2,027	2,157	2,507	2,521
GNP*						
Billion Current $	211	285	398	504	676	977
Billion Constant 1958 $	313	355	438	488	610	724
FRB Index† (1957-59=100)	60	75	97	109	143	168
Motor Vehicle Registration (Millions)	34.2	49.2	62.8	74.5	91.8	109.0
Passenger Cars	28.2	40.3	52.1	62.3	76.6	89.9
Trucks and Buses	6.0	8.9	10.7	12.2	15.2	19.1

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* Gross National Product--a measure of total goods and services produced by the Nation.

† Federal Reserve Board Index--a measure of the Nation's industrial production.

TABLE 38

FACTORS AFFECTING U.S. GASOLINE DEMAND

	1946	1955	1965	1970
Annual Gasoline Usage				
Barrels per Person	4.94	7.36	8.61	10.28
Barrels per Household	19.20	27.40	28.70	33.41
Gallons per Car	665.00	664.00	649.00	735.00*
Number of Passenger Cars (Millions, Year End)	28.20	52.10	76.60	89.86
Persons per Car	5.05	3.20	2.61	2.29
Cars per Household	0.75	1.07	1.29	1.42
Gasoline Demand (MB/D per Billion $ GNP)	9.55	9.18	7.19	6.22
Population (Midyear Millions) Total	141.94	165.93	194.57	205.40

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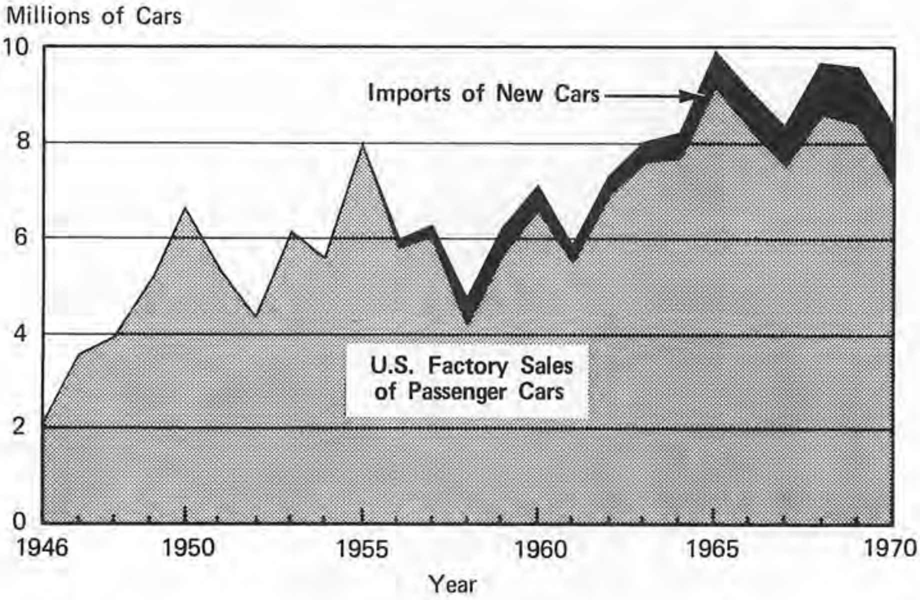
* Estimated.

Increases in income and availability of credit permitted many families to own a car who previously could not. A further stimulus to increased car ownership has been the large gain in people reaching driving age. Thus, while U.S. population growth between 1946 and 1970 was almost 45 percent, the growth in car registrations from 28.2 to 89.9 million was a 219-percent increase, and the gain in automotive gasoline consumption from 1,920,000 to 5,785,000 barrels per day was a 201-percent increase.

The United States has become a nation on wheels. Four out of every five workers use an automobile for commuting to and from work. One-fourth of the workers belong to a car pool. More than 80 percent of the vacationing public use their own automobiles for transportation. Almost one-half of all automobile travel is used for the purpose of earning a living. One-third of automobile travel is used for family business (shopping, medical, etc.), while the remainder is for family, social and recreational activity. Figure 72 shows an increase in U.S. car sales (domestics and imports) since 1946 from 2.2 million units through the 1968 peak of 9.7 million to the calendar year 1970 level of 8.4 million units.



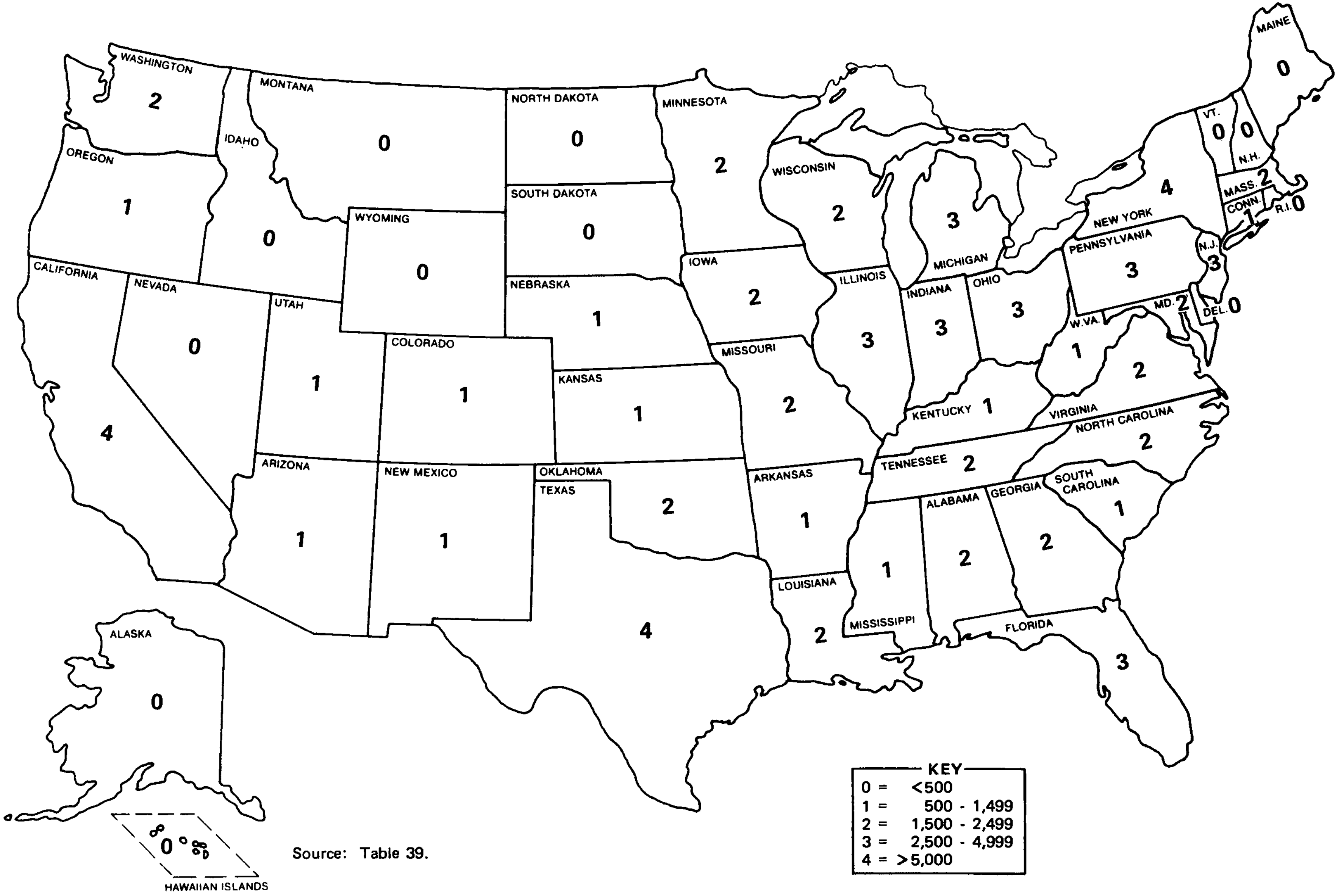
Source: Automobile Manufacturers Association, Inc., *Automobile Facts and Figures* (Detroit, 1966).

Figure 72. Passenger Car Sales.

The total mileage traveled has increased in direct ratio to the number of cars, since the mileage per automobile has not changed much over the years. This has caused some congestion on the highways and city parking problems; nevertheless, automobile travel continues to grow. Figure 73 and Table 39 indicate the geographic distribution of automobile use.

When all of the new federal highways are open, greater travel, including longer vacation trips, seems likely. While the annual growth in gasoline is affected by general business, there has not been a decline in demand in any year since the war, in spite of several recessions.

During the postwar period, truck usage rose sharply on the highway, on the farm, and for city delivery. Truck registrations have nearly tripled, from 6 million in 1946 to almost 18 million in 1970.



Source: Table 39.

Figure 73. Total Gasoline Consumption by State--1970* (Million Gallons).

TABLE 39

TOTAL GASOLINE CONSUMPTION IN THE UNITED STATES, 1970
(Thousand Gallons)

Alabama	1,602,530	Montana	425,250
Alaska	102,081	Nebraska	849,435
Arizona	951,252	Nevada	323,099
Arkansas	966,813	New Hampshire	438,409
California	9,227,084	New Jersey	2,835,439
Colorado	1,113,951	New Mexico	564,100
Connecticut	1,219,103	New York	6,290,640
Delaware	264,812	North Carolina	2,421,314
District of Columbia	239,598	North Dakota	380,524
Florida	3,307,979	Ohio	4,599,796
Georgia	2,318,640	Oklahoma	1,574,561
Hawaii	228,439	Oregon	1,064,099
Idaho	411,231	Pennsylvania	4,345,803
Illinois	4,423,552	Rhode Island	346,075
Indiana	2,521,873	South Carolina	1,220,789
Iowa	1,526,692	South Dakota	426,007
Kansas	1,378,282	Tennessee	1,816,867
Kentucky	1,443,686	Texas	6,393,505
Louisiana	1,502,040	Utah	603,624
Maine	471,249	Vermont	214,810
Maryland	1,580,301	Virginia	2,136,201
Massachusetts	2,095,440	Washington	1,542,262
Michigan	4,183,989	West Virginia	694,111
Minnesota	1,907,290	Wisconsin	1,948,207
Mississippi	1,047,966	Wyoming	255,550
Missouri	2,394,687		
		TOTAL	92,051,037

Source: American Petroleum Institute Division of Statistics and Economics. Total gasoline includes motor gasoline, aviation gasoline and U.S. Government consumption. It does not include all naphtha used as petrochemical feedstock.

Air travel developed rapidly after the war, causing substantial increases in demand for aviation gasoline. This demand jumped from 35,000 barrels per day in 1946 to 192,000 barrels per day in 1955. Then the jet age in domestic airline travel began, creating a need for an entirely different fuel in the aviation business. Faster and larger commercial planes have continued to increase demands. Private and business planes had grown substantially, to almost three-fourths of the 122,917 planes in the "general aviation" category at the end of 1970.

The kerosine/turbine fuel demand, nonexistent in 1955, jumped to 91,000 barrels per day in 1960, and in 1970 reached 716,000 barrels per day. The U.S. passenger miles traveled in 1969 came to 153,843 million compared with 25,200 million in 1955 and 10,700 million in 1950. World travel amounted to 341,313 million miles in 1969. Thus, the U.S. total was 45 percent of world travel in that year, whereas our population is only 5.8 percent of the world. Even with Americans traveling almost as much as the rest of the world combined, air travel in the United States is still in the early stages of growth. The annual consumption of turbine fuel in 1970 amounted to 53 gallons per person--enough for only about 2.75 minutes of jet or turboprop flying time per year.

Heating demand for distillates increased sharply after the war, chiefly because of a switch from coal in existing homes.[299] The postwar gain averaged 6.3 percent per annum between 1946 and 1965. Since 1965 the rate has been 1.5 percent. At the end of 1946, there were 2.7 million homes in the United States centrally heated with oil. This number jumped to 10.4 million in 1965, and to 11.2 million in 1969. In addition, many homes are heated with space heaters. Today almost two out of every three homes are heated by gas.

Diesel demand has shown great increases since the war. In 1946, it amounted to about 150,000 barrels per day for all uses. By 1969, the demand climbed to about 964,000 barrels per day. The chief uses were 380,000 barrels per day for trucks and buses on highways; 135,000 barrels per day for nonhighway stationary diesel engines that are used for road and building construction, etc; and 449,000 barrels per day for the railroads.

The demand for residual fuel oil in the United States for heating, industrial, military and utility use forms an important part of domestic energy demand. Figure 74 and Table 40 indicate the geographical distribution of this demand in 1968.

Heating demand for residual oils in large office buildings, apartments and hotels rose substantially after the war because of the large increase in office space and large apartment buildings. In 1946, consumption for heating averaged 136,000 barrels per day and by 1969 the volume increased to 488,000 barrels per day, a gain of 5.7 percent per annum. Demands for uses other than heating have been affected by the elimination of railroad usage because of the postwar switch from steam engines to diesel locomotives. In 1946, railroads consumed 275,000 barrels per day of residuals and this declined to 9,000 barrels per day in 1969. However, the demand for residual fuels took a sharp turn upward in the last few years as a consequence of industrial and power plant shifts in demand from coal and shortfall in expectations for completion of nuclear fuel plants. This trend is likely to be accelerated because of the probability that gas supplies will not keep pace with the demand for gas. As a consequence, the U.S. demand for residual fuel oil, which had experienced an average annual growth of 1.9 percent, grew 8 percent in 1969 and over 11 percent in 1970.

LPG is a large volume product that has experienced an overall growth rate of 9.8 percent per annum since World War II and 5.0 percent since 1960. Demands for LPG as raw material for petrochemical manufacture have been increasing at a rate of 10.7 percent per annum since 1960. Residential and commercial space heating and cooking usage have grown at a 10.6 percent rate. In the 1950's, the use of LPG for engine fuels increased from 130 to 850 million gallons a year.

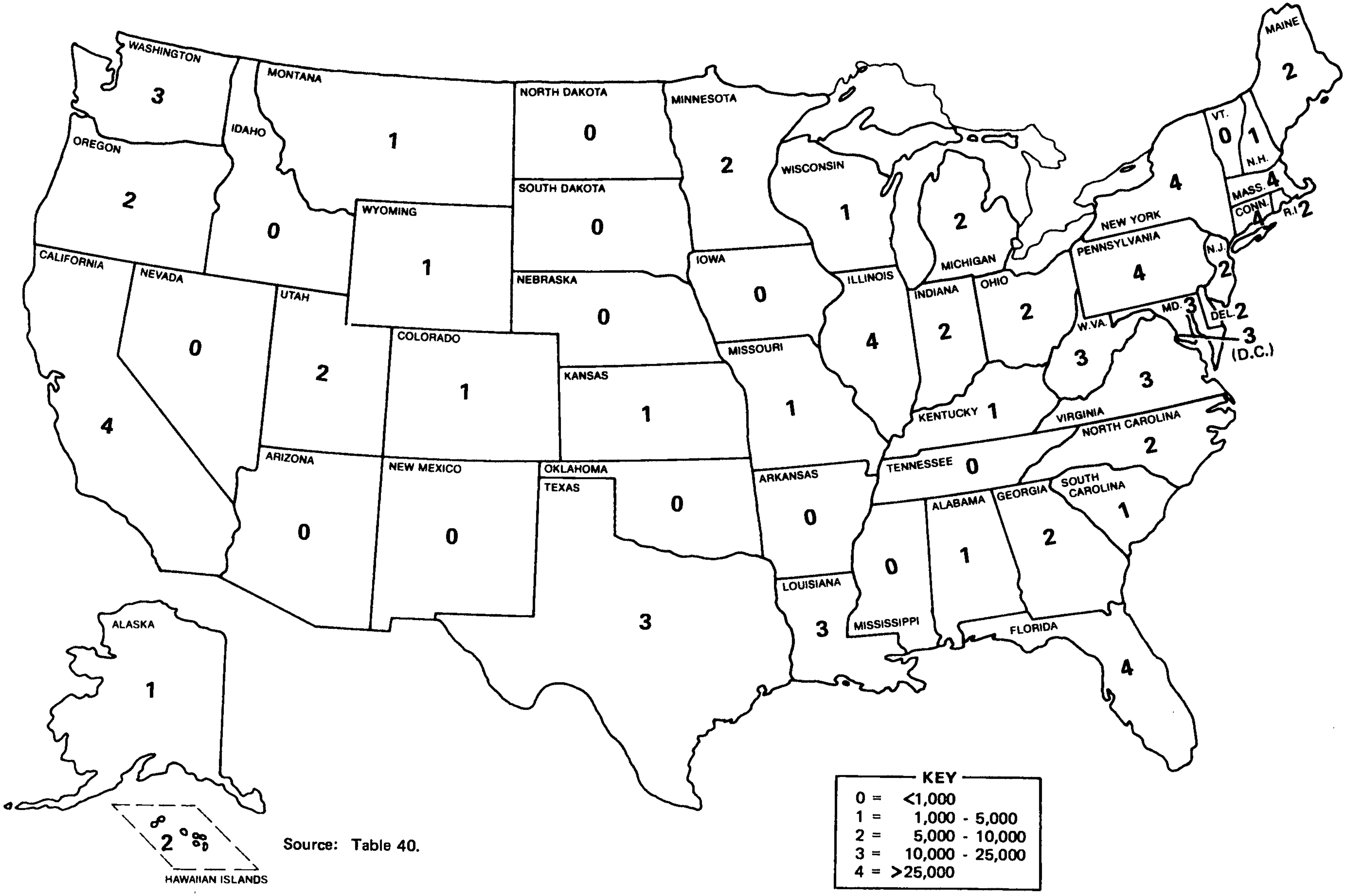
Section 2.
PRODUCT DEVELOPMENT--CHARACTERISTICS AND IMPROVEMENTS

Since World War II there has been a steady upward trend in the quality of petroleum fuels, from gasoline and jet fuels for transportation to residual fuels for industry and distillate fuels for the home. Intense competition in the petroleum industry has led to higher-quality products as well as to the introduction of numerous additives to improve both the performance and life of automotive and aircraft engines and the performance of petroleum products in general. Equipment designers were quick to modify their products to take advantage of fuel improvements, with the result that a new era was begun in reliable, high-performance transportation and in increased heating and power efficiency.

A. Motor Fuels

1. Motor Gasolines

Following World War II, motor gasoline changed from a relatively simple mixture of petroleum fractions into a complex product made by careful blending of many



Source: Table 40.

Figure 74. Sales of Residual Fuel Oils (All Uses), by States, 1969 (Thousands of Barrels).

TABLE 40

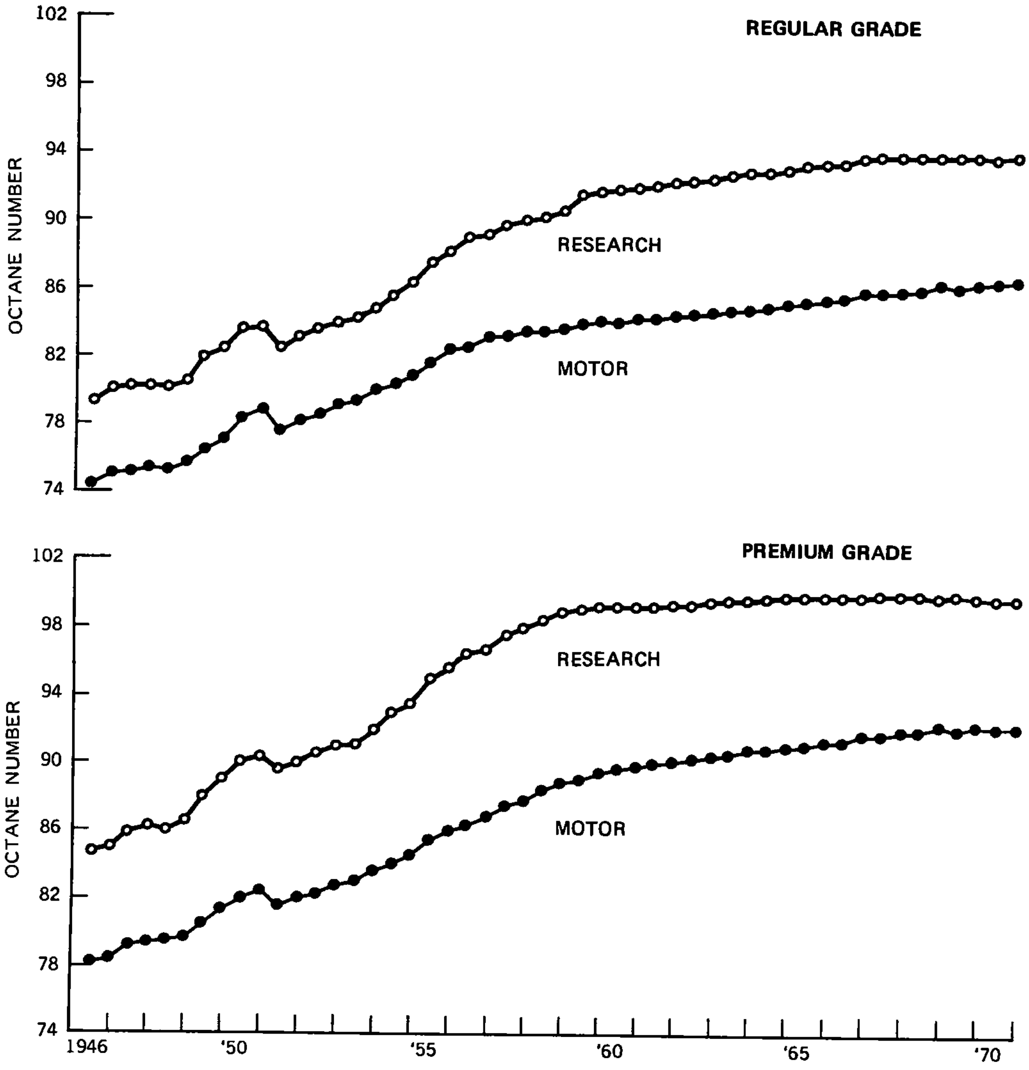
SALES OF RESIDUAL FUEL OILS (ALL USES), BY STATES, 1969
(Thousands of Barrels)

Alabama	3,392	Missouri	3,640
Alaska	1,056	Montana	1,524
Arizona	156	Nebraska	731
Arkansas	501	Nevada	105
California	73,638	New Hampshire	4,434
Colorado	2,103	New Jersey	73,697
Connecticut	32,924	New Mexico	95
Delaware	5,893	New York	136,327
District of Columbia	11,042	North Carolina	6,112
Florida	44,523	North Dakota	548
Georgia	9,020	Ohio	6,183
Hawaii	9,997	Oklahoma	683
Idaho	402	Oregon	6,796
Illinois	25,456	Pennsylvania	51,489
Indiana	9,519	Rhode Island	9,147
Iowa	393	South Carolina	4,138
Kansas	1,438	South Dakota	181
Kentucky	1,043	Tennessee	786
Louisiana	11,509	Texas	14,110
Maine	9,467	Utah	6,030
Maryland	15,321	Vermont	677
Massachusetts	73,572	Virginia	22,701
Michigan	6,704	Washington	11,011
Minnesota	5,165	West Virginia	1,976
Mississippi	688	Wisconsin	2,135
		Wyoming	2,351
		TOTAL	722,529

Source: American Petroleum Institute, *Petroleum Facts and Figures* (Washington, D.C., 1971).

intermediate refinery stocks. Where straight-run and thermally cracked stocks were the primary gasoline components before the war, today we find many different refining processes producing specific hydrocarbon types for blending into motor gasoline. Among these, catalytic cracking, alkylation, catalytic reforming, polymerization, isomerization and hydrocracking are the most common. Consequently, the refiner is able to exercise close control over the final product to give it desired properties. In addition to processing, he also has a large selection of additives available that can be used to provide specific control over final product performance.

One of the more important changes in gasoline quality during the past quarter century has been the vast improvement in antiknock quality as measured by research and motor octane number. This trend is shown in Figure 75 for both premium and regular grade gasoline. The immediate benefit of the antiknock improvement in gasoline has been to enable the automobile industry to produce a



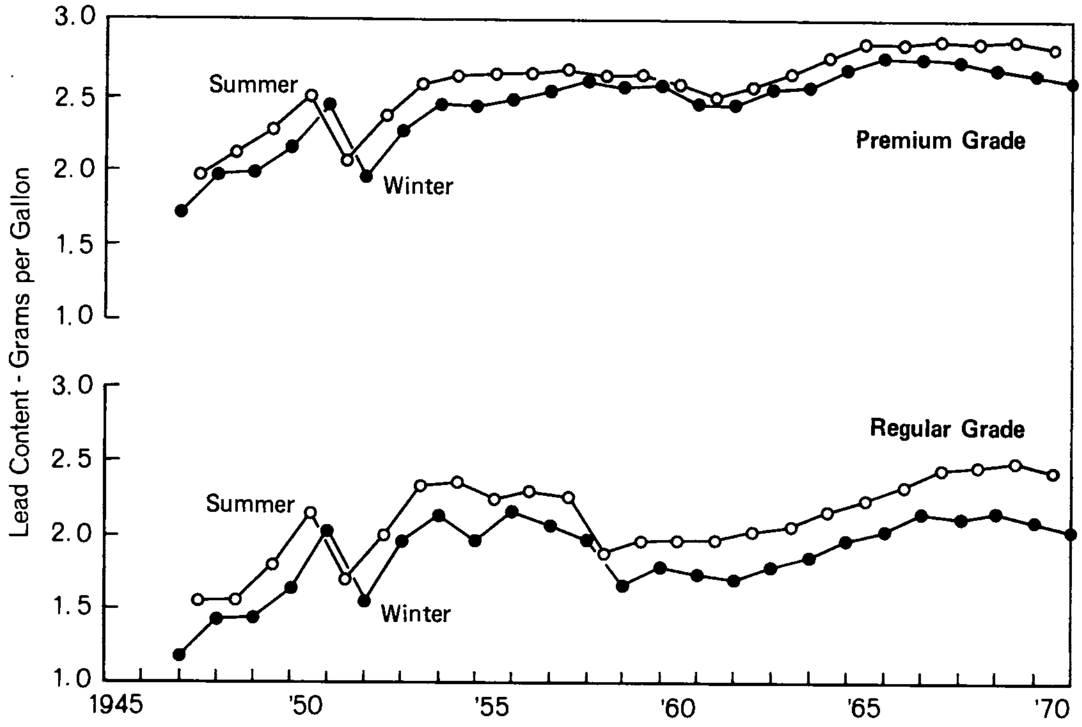
Source: U.S. Bureau of Mines, "Motor Gasolines," *Mineral Industry Surveys;* Research Council reports.

Figure 75. Trends in Octane Numbers of Motor Gasolines.

high-compression engine either with increased fuel economy or increased power, or both, depending upon the individual consumer's desires. The trend in the lead content of gasoline is shown in Figure 76.

Most of the octane increase in gasoline during the past 15 years has been achieved through new processes introduced into refining technology rather than by increasing the amount of lead alkyls added to the blend. A major contributor has been the octane improvement of base stocks provided by more extensive use of catalytic cracking. Development of an efficient catalytic reforming process has made additional quantities of high-octane blending stocks available, and alkylation plants idled by a decline in the demand for aviation gasoline have been pressed into motor gasoline production.

Although the weight of lead alkyl added to gasoline has not increased significantly, two important developments have made the antiknock additive more effective. First, desulfurization of gasoline base stocks was developed to lower the sulfur content of the finished product. Since sulfur detracts from the ability of lead alkyls to increase octane, this process increased the octane gain from the same concentration of tetraethyl lead (TEL). A second development was the introduction of other lead alkyls, such as tetramethyl lead



Source: U.S. Bureau of Mines, "Motor Gasolines," *Mineral Industry Surveys.*

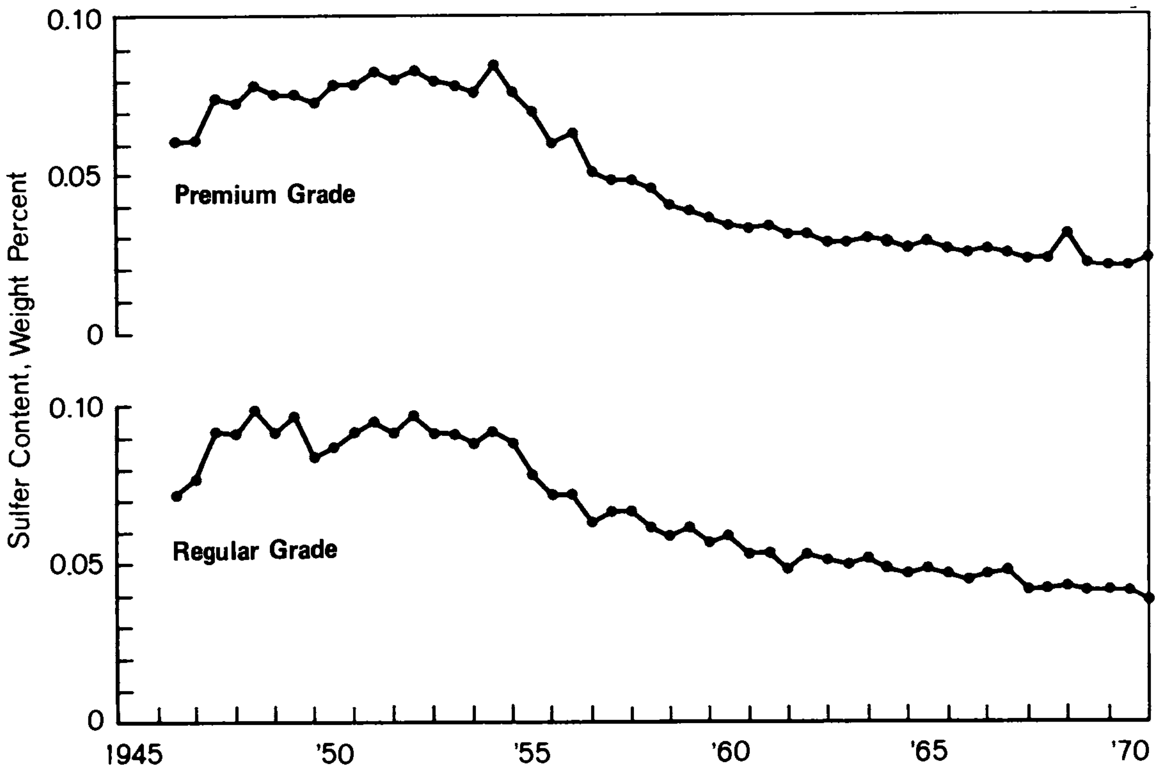
Figure 76. Trends in Lead Content of Motor Gasolines.

(TML), as antiknock additives which offer an economic advantage over TEL in certain gasolines. Third was a reduction in sensitivity of gasoline occasioned by a greater use of iso-paraffins with a consequent reduction of other components.

At present, active consideration is being given to regulations limiting lead alkyl content of motor gasolines. It presently appears that satisfactory operation of advanced emissions control systems utilizing catalysts will require low-lead or unleaded fuels. Voluntary action on the part of the oil industry has already resulted in general availability of low-lead and unleaded gasolines. This trend will undoubtedly continue, bringing about increasing supplies of these types of fuel and will result in major investments for new refinery facilities.

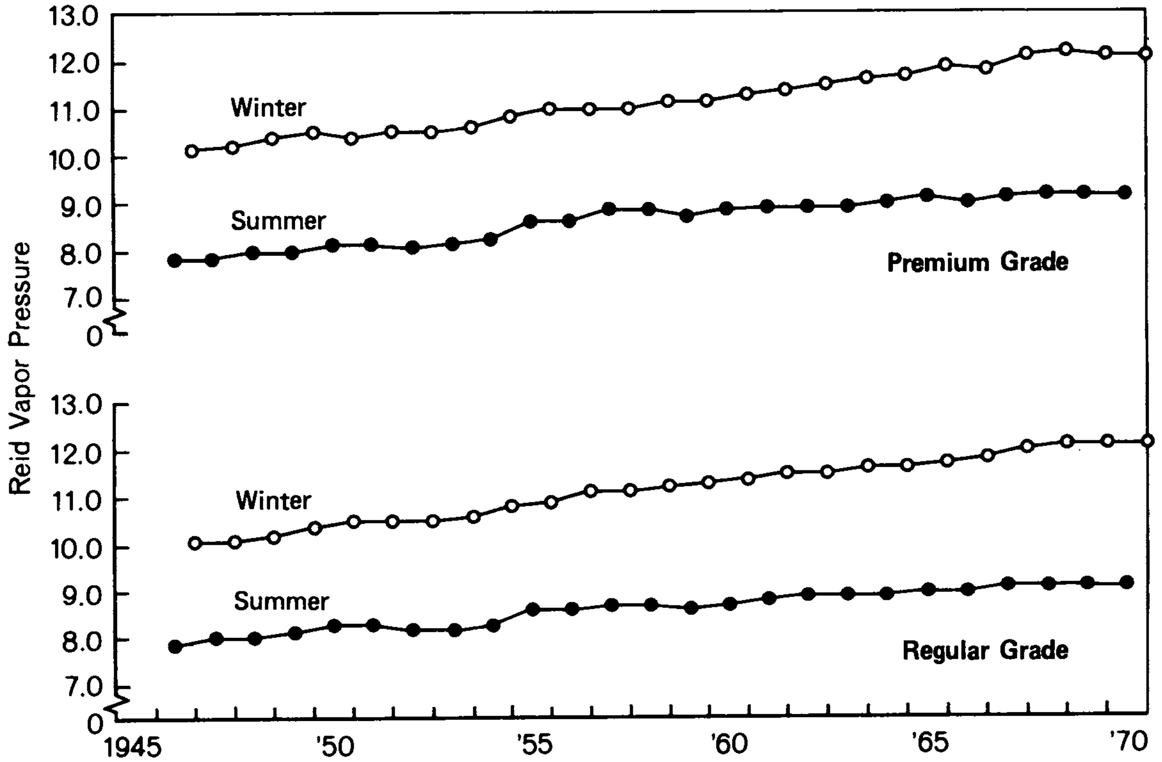
Reduction of sulfur in motor gasoline gave advantages in addition to improvement in lead response. Inasmuch as sulfur in gasoline is an important contributor to engine wear and deposits, the reduction in sulfur itself represented a significant quality improvement. Figure 77 shows the reduction in average sulfur level in finished premium and regular gasolines since 1946.

More intense processing and more natural gas liquids production have increased the availability of low-boiling base stocks, with the result that volatility of motor gasoline has also steadily increased. This trend toward more front-end volatility is shown in Figure 78. The changes in volatility have improved performance characteristics markedly. With the more volatile gasolines, starting is easier, warmup is quicker, performance during warmup is better, there is less crankcase dilution, and, to a lesser extent, an improvement has been made in cylinder deposits and engine wear. On the other hand, more volatile gasoline increases evaporation losses and also the occurrence of vapor lock and carburetor icing. It should be pointed out that the fuel systems of vehicles have also been modified to permit handling of the higher front-end volatility gasolines without encountering operational difficulties such as vapor lock.



Source: U.S. Bureau of Mines, "Petroleum Products Survey," *Mineral Industry Surveys* (June 1971).

Figure 77. Trends in Sulfur Content of Motor Gasolines.



Source: U.S. Bureau of Mines, "Petroleum Products Survey," *Mineral Industry Surveys* (June 1971).

Figure 78. Trend in Motor Gasoline Volatility.

Volatility has been optimized to give peak engine performance, even to the extent of controlling volatility by geographical areas and seasons.

Prior to 1950, relatively few additives were used in gasolines. TEL was the only antiknock compound in general use, and various antioxidants and metal deactivators were used to improve storage life. Dyes were used at the request of the Surgeon General to denote the presence of lead alkyls in gasoline, as well as to distinguish grades. Since then, development of new additives has resulted in additional improvements in motor gasoline quality.

In 1953 the first detergent additive was used in gasoline, and the use of detergents has now been expanded so that many of today's gasolines contain detergents or dispersants. These materials minimize deposits in the venturi and throttle body sections of carburetors and thus help maintain a uniform carburetor adjustment. They are also a significant quality improvement because, by maintaining proper idle, they improve gasoline mileage in town driving, reduce the cost of carburetor maintenance and reduce exhaust pollutants.

Many of the carburetor detergents also have the ability to function as anti-icing additives. Carburetor icing can occur in cool, wet weather when the evaporating gasoline causes atmospheric moisture to form ice around the throttle valve and starves the engine for air. Other anti-icing additives such as freezing-point depressants (alcohols, glycols, etc.) are sometimes employed. Recent-model cars are less prone to encounter carburetor icing problems than earlier cars because of design improvements (more heat to the carburetor, faster idle speeds, etc.).

Intake system deposit (ISD) control additives have also been developed to control intake system and valve deposits. These additives are coming into wider use because of their importance to the maintenance of low emissions during the life of the car.

Most modern gasolines have the ability to reduce corrosion in fuel systems, usually as a plus feature of the surface-active detergent deicers. Some gasolines also contain special rust preventers. Rust prevention is generally required in petroleum product pipelines.

Another additive achievement was made in 1953 with the use of tricresyl phosphate and other combustion-control additives in gasolines. This material has the ability to modify combustion-chamber deposits and reduce their tendency to initiate pre-ignition or spontaneous combustion of the fuel-air charge. Thus, phosphorous compounds control deposit-induced ignition, reducing the so-called "wild ping" or intermittent knock, and reduce "rumble," a very loud engine noise caused by a rapid rate of pressure rise in combustion chambers. Phosphorous compounds also reduce spark-plug fouling. The need for and the effectiveness of phosphorous compounds increase with higher compression ratios. The effects become noticeable in some vehicles at 10:1 to 11:1 compression ratios and were spectacular in experimental 12:1 compression-ratio engines. Many premium gasolines have phosphorous additives to control engine noise. This, too, is an important consumer benefit, as those phenomena which lead to engine noise also can lead to engine deterioration.

This progress in additive use is most impressive when it is recognized that the introduction of a new additive in gasoline is a major research undertaking. In each instance it is preceded by months, sometimes years, of research and development work with extensive field testing before the additive becomes a commercial reality.

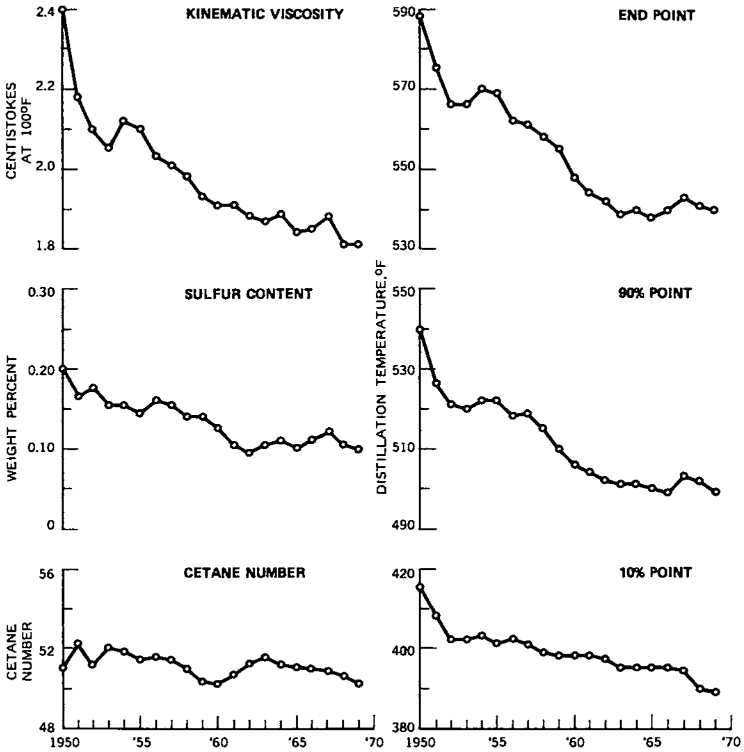
Another improvement in gasolines has been the reduction of trace contaminants such as dirt and rust. These contaminants have become less of a problem as a result of the use of corrosion inhibitors and fine filters in automotive fuel systems and, in some cases, special filters installed in service station pumps.

It has been established that uncontrolled gasoline evaporation and automobile exhaust emissions are major contributors to photochemical smog. Numerous companies and government agencies have been and are conducting research to lower these emissions to a greater extent than has already been accomplished. Those involved in this research have expressed confidence in further success; but, at this time, it is not clear which of several possible solutions is the best or has the best chance of being successfully developed. Changes in fuel composition have already been made, but the full extent of such changes that may be required is not at all definite at this time. The subject of trends in emissions from use of motor gasolines and of the characteristics of these fuels affecting engine performance and evaporation and emissions is reviewed in detail in the next chapter.

2. Diesel Fuels

Like motor gasolines, distillate diesel fuels for use in automotive diesel engines have been changed during the past several years to meet the requirements imposed by changes in engine design and operation. Major performance factors of diesel fuels are characterized by sulfur content, cetane number as a measure of ignition quality, viscosity (which indicates fluidity or flow at low temperatures) and volatility.

The most significant improvement in diesel fuels has been realized by reduction of sulfur content brought about by the use of hydrogen treating in refineries. Sulfur contributes to engine deposits and wear, and its reduction is a significant improvement. In addition, fuels have been gradually reduced in viscosity and increased in volatility, which has decreased engine deposits, smoke and odor. This steady quality improvement in key properties is shown for a typical high-volume diesel fuel in Figure 79. Other types have experienced similar improvement over this period.



*Formerly listed as Grade 1-D Diesel Fuel. Now designated "City Bus" Fuel.

Source: U.S. Bureau of Mines, "Diesel Fuel Oils," *Mineral Industry Surveys* (1965).

Figure 79. Trends of Some Properties of Type C-B* Diesel Fuel Oils.

Railroad diesel fuels have not changed significantly with time. Some railroads operate on special economy-grade fuels that have much broader volatility and lower cetane numbers than their automotive counterparts, and almost always contain large percentages of cracked stock. The large diesel engines in railroad service are less sensitive to fuel properties than their automotive counterparts and can operate satisfactorily on fuels with less exacting specifications.

Most diesel engines in truck service can operate satisfactorily on truck and tractor fuels available today. However, there is a wide range of fuels possible under this classification, and variations within the classification can have significant effect on a given engine's performance. With engine design emphasizing higher power output, reduced smoke and maximum economy, more uniform fuel quality is desirable. In order to optimize performance, fuel specifications with narrower gravity and volatility requirements are likely in the future.

As in the case of gasolines, the use of additives has become much more common in diesel fuels. Cetane improvers, largely alkyl nitrates, provide ignition-quality improvement. Ignition quality influences ease of starting, roughness of operation, and exhaust smoke.

A variety of additives are used to improve storage stability and service operation of diesel fuels. Polymeric and other types of additives have been used as detergents and dispersants. The detergents have the ability to maintain fuel injection nozzle cleanliness and will markedly increase operating time between nozzle overhauls. The so-called dispersants affect fuel filter life, and a similar improvement has been achieved here. Many diesel fuels also contain rust preventives.

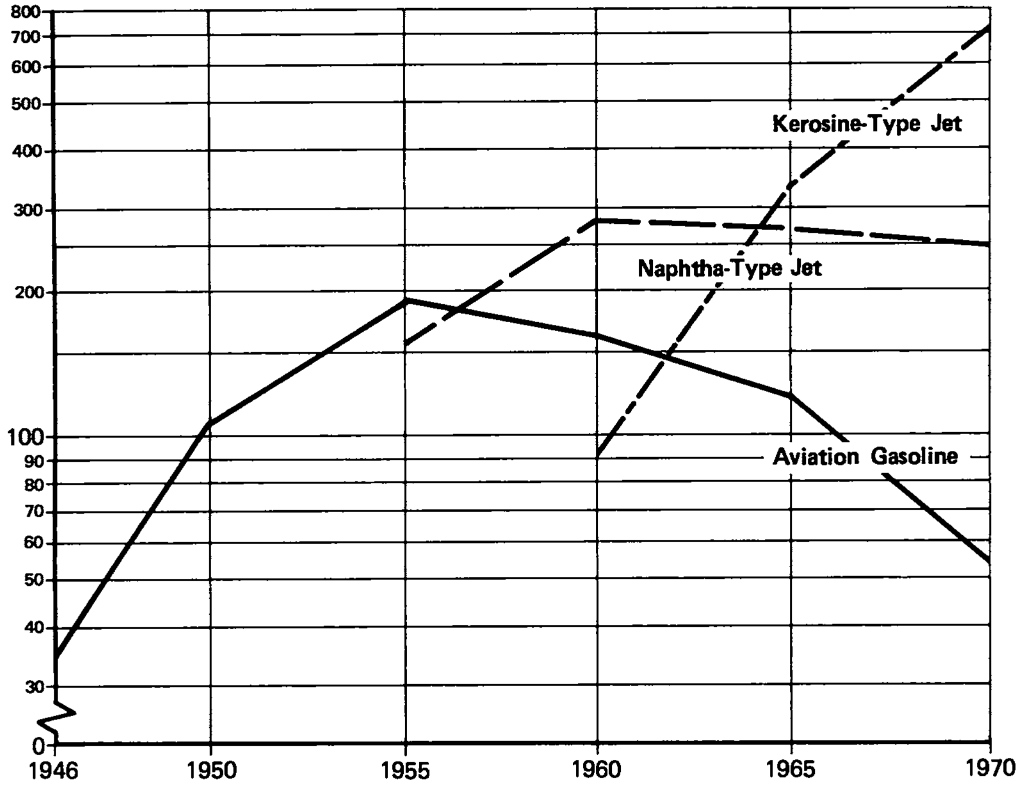
The high demand for diesel and jet fuels has made it difficult to obtain suitable low-temperature flow characteristics by stock selection. This has led to increased use of pour-depressant additives. Several of these materials, both polymeric and nonpolymeric, have the ability to greatly reduce pour points, resulting in substantial improvement in flow through distribution and truck piping systems. However, their effect on cloud point or the first appearance of wax crystals, which can cause filter plugging under cold conditions, is small. This has limited their acceptance; but as experience is obtained, improvements will be made and their use should increase.

Recent air pollution laws have led to an increased interest in antismoking additives. The most functional of these are overbased barium compounds which are effective at concentrations of about 1,000 parts per million. Effective concentrations of the barium additives are quite costly, and the ash contributed by the barium salts could be a problem in some engines as well as a health problem. Two other types of additives are emerging from the development stages. They are biocides to prevent bacterial attack on the fuel, and masking agents to improve the odor of exhaust fumes in city bus service.

The number and variety of available diesel-fuel additives have enabled the petroleum industry to significantly increase the quality of diesel fuels. Further improvements are anticipated over the next several years.

3. Aircraft Fuels

Two types of aircraft fuels are used in the United States today. These are aviation gasolines (AVGAS) for spark-ignition engines and jet fuels for aircraft turbine (turbojet and turboprop) engines. Figure 80 shows the U.S. demand for aviation fuels since 1946. Note in the late 1950's U.S. demand for jet fuels exceeded the demand for AVGAS and has steadily increased since then.



Source: Table 36.

Figure 80. Trends in U.S. Demand for Aviation Fuels.

a) Aviation Gasoline

The American Society for Testing Materials in 1947 issued specifications for aviation gasolines, Grade 91-98 and Grade 100-130. (The first number refers to antiknock performance under lean conditions and the second number under rich conditions.) Since then, specifications for three additional grades were added:

Grade 115-145	(1948)
Grade 80-87	(1951)
Grade 108-135	(1953)

Other changes made in the specifications included: (1) dyes for color identification of the five grades, (2) improved test methods, and (3) an increase in the number of approved antioxidants from three to five.

Quality control in aviation gasoline is even more critical than in motor gasoline, since engine failure is a much more serious matter. Antiknock control is especially critical because, unlike the motorist, the pilot is unable to hear an engine knock over the high noise level. Volatility, freezing point, heat of combustion and oxidation stability are all very important to the AVGAS consumer. Quality-control surveillance and close process control have enabled the industry to produce a uniform-quality premium product.

Aviation gasolines contain up to 4.6 milliliters TEL per gallon (Grade 115-145). Ethylene dibromide is added to scavenge the lead; it has been found more effective under high-load aircraft conditions than the chloride/bromine scavenger mixtures used in motor gasolines. Other alkyl leads, TML or methylethyl lead compounds, are not used in aviation gasolines.

Some hydrocarbon constituents of AVGAS tend to oxidize during storage at ambient temperature. The products of oxidation--fuel-soluble and fuel-insoluble gums--interfere with metering of the fuel to the engine and must be controlled. Trace amounts of certain amine and phenolic compounds have been found to be particularly effective in this service.

b) Jet Fuels

Commercial kerosine was first used as a fuel in early development work on jet aircraft in the United States. The choice of kerosine over gasoline was based on its low volatility to avoid occurrence of vapor lock under certain flight conditions and its availability as a commercial product of uniform characteristics. JP-1,* the first military jet fuel, was highly refined kerosine having a very low freezing point (-76 degrees Fahrenheit).

Kerosine from selected crudes high in naphthenes was the only fuel having the low freezing point (-76 degrees Fahrenheit) specified for JP-1. The demand for this fuel increased very rapidly and the Military Petroleum Advisory Board took a long, hard look at the appetite of jet engines, together with the availability of JP-1 and AVGAS. The Board made a strong recommendation for the development of a military jet fuel having greater availability in wartime than either JP-1 or AVGAS. The second try at a jet fuel was JP-2, but it did not have the desired availability. Next was JP-3 fuel; it included the total boiling range of kerosine and gasoline. A cooperative program of testing by the Coordinating Research Council demonstrated that the high vapor pressure of JP-3 (Reid vapor pressure [RVP] of 5 to 7 pounds) resulted in vaporization of the fuel during climb to altitude. In addition, some fuels foamed excessively during vaporization, so that very large losses of liquid could occur along with the vented vapors.

To overcome the disadvantages of JP-3, the Reid vapor pressure was reduced to 2 to 3 pounds and JP-4 was developed in 1951. The new fuel is a blend of 25- to 35-percent kerosine and 65- to 75-percent gasoline components, and has proved quite satisfactory for military requirements.

One important Navy turbine fuel developed for carrier operation during the Korean War was a mixture of a special kerosine and AVGAS. AVGAS is stored in tanks in the central zone of carriers to minimize the possibility of hazardous fuel leaks in the event of battle damage. Space in this area is in high demand for other purposes, thereby limiting available storage space for AVGAS. The problem was solved by the development of JP-5 fuel for aircraft carriers. This fuel is a special, 140-degree-Fahrenheit flash-point kerosine, and because of its low volatility can be stored safely in outer tanks of carriers. When mixed with AVGAS, JP-5 gave a fuel similar to JP-4. Later the Navy eliminated the AVGAS mixture and used the JP-5 alone.

Commercial airline jet fuels in the United States fall within the general framework of ASTM Jet A, A-1 and B fuels. Jet A and A-1 are of the kerosine type. Jet B corresponds to the military JP-4 fuel. Volume demands for Jet A and A-1 are large, but small for Jet B.

Jet fuel fulfills a dual purpose in the aircraft. It provides energy and serves as a coolant for lubricating oil and other aircraft components. Exposure of the fuel to high temperatures may cause the formation of gums (organic residue), which reduces the efficiency of heat exchangers and clogs filters and valves in aircraft fuel-handling systems. Thermal stability is the resistance to formation of gums at high temperature. The JP-4, JP-5 and equivalent commercial fuels have satisfactory thermal stability for aircraft operating at speeds up to about Mach 2. Future jet aircraft operating at higher speeds (e.g., Mach 3) may expose the fuel to greater thermal stresses and may require a more stable fuel. The development of Mach 3-4 turbojets, Mach 6+ ramjets, and rockets using hydrocarbon fuels will pose additional problems on fuel capabilities.

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*"JP" = jet propulsion.

An attractive method of improving jet fuel quality is through the use of additives. The more common additives are antioxidants, copper deactivators, corrosion inhibitors, anti-icing additives and additives to decrease resistivity of the fuel so that electrostatic hazards will be reduced.

4. Other Petroleum Motor Fuels

LPG has been used as a motor fuel since the late 1920's, having received attention early as a farm tractor fuel where the same fuel was being used for other applications on the farm. In the 1950's the use of LPG for engine fuel increased from about 130 to 850 million gallons a year. Much of this increase was used in bus, truck and taxi fleet operations which had a central servicing center where fueling was done. The use of methane, usually in the form of compressed natural gas (CNG), as a motor fuel is a recent development proposed for urban use in service vehicle fleets because of the reductions in pollutant emissions obtainable by the use of this fuel.

B. Heating and Industrial Fuels

In 1918, the first fully automatic oil burner appeared on the market, initiating a vast expansion of use of burner fuels.[300] Today these fuel oils, generally classified as either distillates or residuals and technically specified as Grades 1 through 6, are specially designed to meet the needs of residential and commercial heating, manufacturing processes, industrial steam and electrical generation, marine engines and many other uses. In addition, there has been a sharp increase in recent years in the use of gas in various forms, such as LPG (familiar to many as "bottled gas"), natural gas and LNG.

1. Distillate Fuel Oil

Distillate fuel oil can be defined as Nos. 1, 2 and 4. Diesel fuel has been discussed previously under "Motor Fuels." Grade No. 2 fuel oil is the designation given to the heating or furnace oil most commonly used for domestic and small commercial space heating and will be reviewed here. This product is a distillate product normally fractionated to a boiling range of about 350 to 650 degrees Fahrenheit.

The period since World War II has seen marked change in both the quality of home heating oils and the manufacturing techniques employed in producing these products. Originally, No. 2 heating oil was composed of selected refinery straight-run stocks blended to meet product quality standards. The resultant product had good stability and was very satisfactory in performance. As the refining industry was called upon to make greater amounts of motor gasoline at higher octane levels, cracking processes were developed to convert virgin gas oils to lighter boiling products. This necessitated the use of increasing amounts of both catalytically and thermally cracked gas oils in finished heating oil blends. Heating oil blending became a more complex operation to maintain a satisfactory quality level without excessive treating expense.

Domestic heating oil must be a clean product. It should form no sediment in storage and leave no measurable quantity of ash or other deposit on burning. Since it is stored at low temperatures, it should be fluid at storage conditions encountered during the winter months. The chemical composition of the product must be controlled to assist in reducing smoke emissions. Sulfur content at one time was not considered a problem; however, it is quite important today. In addition, domestic heating oils must satisfy several other requirements that were not necessary prior to World War II. The fuel must have a liqht color, an attractive appearance and an acceptable odor. It is these properties, along with sulfur removal, which have undergone the greatest change in the past 20 years.

The first cracking process to be used was thermal. This process achieved the fundamental objective, more and higher-octane gasoline, but yielded a high percentage of olefinic material. This type of compound was not particularly objectionable in gasoline; however, it produced instability in fuel oils. Distillate fuels containing high percentages of cracked stocks tended to form gum. As octane requirements for motor gasoline went higher, catalytic-cracking processes were installed. Fuel oils produced from catalytically cracked distillates were high in aromatic compounds. These oils were not as stable as straight-run materials and were more difficult to burn in older equipment, although they give no problem in modern burners.

The oil industry worked in several directions to correct the quality problems associated with the extensive use of cracked distillates. New treating processes, improved burner design and the development of additives all progressed simultaneously. Refiners worked closely with equipment manufacturers in the development of improved combustion devices to handle adequately the fuels that were more difficult to burn. These developments have helped to reduce emissions from combustion sources through more efficient fuel usage. At the same time, the industry began to develop and use additives to improve stability. Another development which proceeded concurrently was the use of caustic washing for fuel oil. Several processes were developed, using either sodium hydroxide or potassium hydroxide in varying concentrations. These processes were preferred over acid treating and proved to be more effective from the standpoint of improving product stability. Many refiners still use a caustic wash in their processing sequence.

In the early 1950's, "reforming" of straight-run gasoline came into widespread use. This process made available to the refining industry large volumes of hydrogen, which had previously been costly to produce. With this relatively cheap, by-product hydrogen, it was possible to adopt hydrogen treating as a means of obtaining further improvements in fuel-oil quality. The primary objective in the hydrogen treatment (including hydrocracking) of heating oils is a reduction in sulfur and removal of small, but objectionable, amounts of nitrogen compounds. This treatment also reduces carbon residue, improves burning characteristics and color stability and reduces sludging tendencies. The problem of sulfur removal has come to the front as refiners have increased processing intensity. Incremental crude has also, in many cases, been high in sulfur, contributing further sulfur-removal problems.

Quality inspections of the feed and hydrogen-treated product from both straight-run and catalytically cracked heating-oil stocks show that critical properties are significantly improved in every case by hydrogen treating. Sulfur reduction is 70 to 80 percent complete. Carbon residue on the 10-percent bottoms fraction of the product is reduced to less than 0.10 percent. The stability tests show that hydrogen-treated products are of excellent quality from the standpoint of both a change in color and in sludge formation during storage. Fuels manufactured by a hydrocracking process are also low in sulfur content.

Hydrodesulfurization of No. 2 furnace oils is currently being done. Besides removing sulfur compounds, these hydrodesulfurization units have the added benefits of saturating most of the olefins or diolefins that may be present in the charge stock and removing some nitrogen and metals from the feed.

Additives developed by the industry have also made a significant contribution to product quality improvement. Of prime importance are the additives used to reduce sludge formation. Most additives of this type are oxidation inhibitors and dispersants which inhibit the formation of gum. A secondary effect of these inhibitors is to keep suspended, in finely dispersed form, the small amount of sediment which still persists. Metallic-based materials were used first; however, today, most inhibitors are nonmetallic amines and polymers. Additives to accomplish other purposes are also quite commonly used. Rust inhibitors, color stabilizers, pourpoint depressants and combustion aids are typical examples.

Minimum standards for domestic heating oils have not changed appreciably during the past few years, even though product quality has improved significantly. The quality improvement trend is perhaps best illustrated by the following table showing average carbon residue and sulfur content of heating fuels produced in the United States since 1956, as indicated by Bureau of Mines surveys.

TABLE 41

AVERAGE CARBON RESIDUE AND SULFUR CONTENT OF HEATING FUELS

Year	Carbon Residue*	Weight % Sulfur
1956	.137	0.330
1957	.128	0.305
1958	.121	0.273
1959	.122	0.260
1960	.116	0.249
1961	.121	0.228
1962	.115	0.229
1963	.114	0.238
1964	.104	0.232
1965	.104	0.241
1966	.095	0.227
1967	.100	0.232
1968	.102	0.220
1969	.106	0.228
1970	.103	0.210
1971	.100	0.210

* Ramsbottom carbon residue on 10-percent residue.

Source: U.S. Bureau of Mines, "Burner Fuel Oils" (Eastern Division Statistics, 1956-71), *Mineral Industry Surveys* (Washington, D.C.).

The above data indicate that during the past 16 years carbon residue has been reduced 27 percent and sulfur content has been reduced over 36 percent. There are undoubtedly other properties which have changed, and the two discussed above are merely illustrative of the technological progress made in the petroleum industry toward the development of higher-quality products.

Now what does this change in product quality do for the consumer, whether he be the general public or the government? In this particular case, improvements in the quality of heating oils have resulted in more efficient, less costly heating systems. The superior processing techniques used today, coupled with the improvements and developments in additives, result in a cleaner-burning product. The reduction in sulfur has been a significant improvement in air pollution. The use of pour-point depressants has improved the low-temperature fluidity of the product, thereby reducing line plugging and other problems associated with outdoor tank storage by the consumer. For those users who have indoor or basement storage, improvement in odor of heating oils is a positive advantage. Better storage stability is also a factor. The frequency of tank cleaning and oil-filter changes has been lessened. All of these improvements are of definite value to the end user.

2. Residual Fuels

Residual fuel oil can be defined as Nos. 5 and 6 heating oils, heavy diesel, heavy industrial and Bunker C fuel oils.

Typically these fuels are used to provide steam and heat for industry and large buildings, to generate electricity and to power ships. Most users of residual fuels have converted their equipment to handle Grade 6, which is less costly, since it utilizes less of the distillate stocks which can be converted more readily into gasoline. In marine circles, heavy bunker fuels are known as Bunker C and generally correspond to Grade 6 fuel oil.

Residual fuels are by their nature high boiling and contain stocks which are difficult to burn quickly under "cold" conditions. Accordingly, such fuels are generally burned in equipment which permits relatively steady operation in an environment where fire-box temperatures can be high.

Since residual fuels compete directly with gas and coal in many areas, the price of the fuel must be competitive. Until recently, it was not economically practical to improve the quality of residual fuels beyond the quality inherent in the crude oils from which they were prepared.

The steady increase in the use of catalytic cracking following World War II had the effect of decreasing the percentage yield of residual fuels as well as changing their makeup. As more high-boiling materials were charged to catalytic cracking, the remaining oil sold as residual fuel became heavier and heavier. Common industry practice was to blend these heavy stocks with a distillate to reduce their viscosity for a salable fuel. Continued work in this field led to the use of mild thermal cracking of the vacuum still bottoms, which yielded a small additional amount of distillate product and reduced the viscosity of the remaining bottoms. Such bottoms required less distillate cutter stock to produce a salable residual fuel oil. This modest advance, using a method developed before the war, known as vis-breaking, could be classed as a beneficial step in residual fuel oil production.

After the war, refining processes in the United States continued to become more efficient in producing the more profitable products. For the year 1970, residual fuels amounted to only 5.8 percent of refinery output. U.S. refiners are continuing to reduce the yield of residual fuels; however, if the current residual shortages and higher price prevail, this trend could be slowed down or even reversed. Fluid and delayed coking are the two processes which are principally used for upgrading the residual fraction. Refiners can also select solvent deasphalting or residual hydrocracking.

Increasing imports of foreign residual fuels has kept the sulfur level fairly constant, and the quality of domestic fuels has remained essentially unchanged during this period. On a worldwide basis, residual fuels do vary considerably in quality. Quality in a given location varies, depending on the crude used and the economy of the country where it is refined.

Most of the advances in residual fuel oil technology since World War II have led to increases in its use and until recently have been nonrelated to its quality. Metals, such as sodium and vanadium, which are commonly found in small amounts in residual oils, can cause fireside tube deposits in boilers, corrosion, and fly-ash air contaminants. Some of the sodium can be removed by water washing and centrifugation. There is no known commercially feasible way to remove metals such as vanadium from residual oils. Fly ash and other solid particulates can be removed from stack effluents by use of electrical precipitation, although some practical problems exist.

On combustion, part of the sulfur in the oil may contribute to boiler-tube deposits; part may be converted to sulfuric acid, leading to corrosion at low temperature points; and the remainder escapes as oxides of sulfur into the atmosphere.

The oil industry and boiler manufacturers have stepped up their efforts considerably in the areas of desulfurizing fuel oil and flue gas and reducing fuel-oil metals content. Several test installations designed to remove sulfur from flue gas are being evaluated. Much work is under way in the research laboratories of both oil companies and boiler-manufacturing companies.

Direct desulfurization of high-sulfur residuals can presently be accomplished only on certain low-metal-content residuals, consequently limiting the volume of low-sulfur material obtained from this process. Low-sulfur residual is also obtained by topping naturally occurring low-sulfur crudes. Residual fuels produced from this type of operation fall in a range of 0.5 percent or below of sulfur, depending on crude source. The volume of material available from these low-sulfur crudes is limited because of their location, principally North and West Africa, and the ever-increasing worldwide competition for these low-sulfur crudes.

The most common method of obtaining 1-percent-sulfur fuels is by blending high-sulfur residuals with desulfurized low-sulfur vacuum distillates. This technique is being used to supply most of the residual fuel to the East Coast markets. Desulfurization of the overhead from vacuum distillation of reduced crude can produce fuel having a sulfur content as low as 0.3 percent; however, the use of only this portion, with no back blending of residual, would greatly reduce the volume of 1-percent-sulfur fuel, which is currently in critically short supply.

Blends of naturally low sulfur fuel oils with others with higher sulfur content (to meet regulations calling for 1 percent) will have lower pour-points than the straight North African crudes and can be handled at temperatures 10 to 15 degrees Fahrenheit lower than the straight North African fuel. Heated lines and tanks are still required, however.

The major benefits of naturally low sulfur fuel oils are reduced slag deposits on superheater tubes or other furnace parts and decreased weight of carbonaceous particles emitted from the flame, because they contain considerably less amounts of ash and asphaltenes.

A large number of additives have been developed for reducing residual fuel oil sludge, tube deposit formation and corrosion, and for increasing combustion efficiency. Additives are also being tested to determine whether they can reduce sulfur oxide emissions. Additives for reducing fireside fouling of superheater tubes by metallic compounds have met with some success, but the fouling problem has not been completely solved. Some of the metallic compounds are corrosive at temperatures in excess of about 1,100 degrees Fahrenheit. Use of additives to reduce this high-temperature corrosion has been reported to be effective in some power plants and gas-turbine operations in the United States and Europe. A number of additives for control of deposits and high-temperature corrosion contain magnesium, calcium, barium, aluminum and silicon compounds, singly or in combination. These metals are intended to raise the melting point of the potential deposit material so that it will not fuse to the tubes but will be carried away in the flue gas as fly ash. Analysis of the possible air contamination from these additive compounds is under way.

Some of the problems in making use of residual oil as a fuel have been alleviated by improvements in burning and handling equipment and engineering practices. Alloys which are more resistant to corrosion have been developed for boiler and turbine components. Better oil atomization has resulted from new burner designs, which has led to improved combustion and reduction of tube deposits. Advances in insulation practices and pump design have made it easier to handle high-viscosity oils. Minimizing excess combustion air has reduced heat loss and the formation of sulfur trioxide, which in turn has reduced corrosion and acid mists escaping to the atmosphere.

3. Liquefied Petroleum Gas

LPG is a specialty product that has taken on increased importance during the past few years. Its most common constituent, propane, does not exist to any great extent in most crude oils. However, the extensive use of catalytic-cracking and catalytic-reforming processes and the growth in hydrocracking have resulted in the production of large quantities of refinery LPG in addition to the production from natural gas processing.

Catalytic cracking of gas oil produces a light ends material which is a mixture of olefins and paraffins. The olefinic portion, propylene and butylenes, is normally converted to gasoline blending components by either polymerization or alkylation. LPG products are produced conjointly in both of these operations. Catalytic reforming of straight-run naphtha is a high-yield process, but appreciable amounts of LPG are produced as a by-product.

Prior to the start of the tremendous growth in the petrochemical industry, namely in ethylene production, the major use of refinery-produced LPG was for household and industrial fuel, although there has long been some use of LPG as a motor fuel, as described in an earlier section.

4. Natural Gas and Liquefied Natural Gas

The ratio of proved natural gas reserves to annual production indicates that these reserves could be depleted in about 13 years. However, there are indications that the FPC now recognizes the need for a more realistic pricing approach to encourage exploration for new reserves. The rapid switch from other fossil fuels to natural gas has merely emphasized this need. Many interstate pipeline companies are unable to accept new customers, and added sales to existing customers must be limited. This situation will exist for a few more years even with higher wellhead prices.

In the last few years, LNG has been performing an increasingly vital role in supplying Europe and Japan with clean fuel. Now, it is turning up in the United States, where it helps utilities meet peak periods of demand amid increasing fuel shortages.

LNG imports are expected to supplement domestic natural gas production in the future, but this is unlikely to be substantial before 1975.

Boston Gas Company, Boston, Massachusetts, imported 4,000 tons of LNG produced in Algeria, to avert a shortage of natural gas in the Boston area during the 1968-1969 heating season. The imports were a one-time expedient for peak use on the 1968-1969 winter days, to serve 32 cities and towns in its marketing area. The first large-scale commercial export of LNG to Japan, about 139 million cubic feet per day, was from Alaskan reserves. In the future, facilities located beyond the service area of gas distribution systems may be able to use gas from LNG storage tanks serviced regularly by the local gas company.

C. Other Petroleum Products

1. Petroleum Solvents

Solvents may be divided into two groups: those that are mixtures of saturated hydrocarbons and those rich in aromatics. In either case, most solvents are comparatively narrow boiling-range fractions. Absence of low-boiling compounds reduces fire hazard, while freedom from high-boiling materials reduces residue left after evaporation. Critical specifications are largely a function of the end product use. Some idea of the large variety of uses and boiling ranges of representative solvents and naphthas is shown in Table 42.

In addition to boiling range, chemical composition can be most important. For example, the aromatic content of any solvent used in a dry-cleaning fluid must be low. Rigid specifications also exist for petroleum solvents used in the

TABLE 42

USES AND BOILING RANGES OF SOLVENTS AND NAPHTHAS

Use of Solvent	Boiling Range (°F)
Perfume extraction	160-260
Castor oil or fat extraction	125-300
Toluene substitute, lacquer formulas, fast-setting varnishes	179-275
Seed extraction	160-300
Rubber cements, tire manufacture	95-370
Lacquers, art leather, rotogravure ink, adhesive tape	95-370
Rosin extraction, shade cloth, rubber dip goods	205-300
Brake linings, leather degreasing, bone degreasing	125-400
Printer's ink, cellulose lacquer diluent	160-370
Paints and varnishes, thinners	105-455
Textile printing and proofing	160-410
Paints and coatings (aircraft), paint removers and solvents	179-410
Paint shop rinsing and cleaning (aircraft)	210-340
Floor coverings, wax, polish, wash for printing plates or rolls	200-410
Dry cleaning, metal and machinery cleaning	200-400
Xylol substitute (in many instances)	275-370
Flat finishes, rustproof compounds	300-455
Synthetic resin thinner	357-410
Wood preservatives	312-650

paint industry. These products must contain no materials that would discolor pigments. If they are to be used in interior paints, they must be free of aromatic hydrocarbons and possess low-odor characteristics. Naphthas and lighter fluids are subjected to some of these same quality requirements. Attention is now also being directed to the control of the photochemical reactivity of solvent emissions into the ambient air, at least in certain portions of the United States such as Los Angeles and San Francisco.

Improvements in quality of solvents and naphthas have resulted from both the development of new techniques and the adaptation of older ones to the manufacture of these products. Technological advances in distillation, both in design procedures and fractionating tray design, have made possible the production of narrower boiling-range products. Development of new solvent extraction and adsorption processes makes possible the separation of compounds by type; i.e., aromatics, paraffins, etc. Modern-day treating systems, such as hydrogenation, have resulted in a reduction of sulfur and improved color and odor. Of equal importance is the development of improved process-control instrumentation. Continuous on-stream analyzers and internal reflux controls for fractionators are but two examples of the progress made in this field during the past 20 years. These control devices make it possible to maintain consistent product quality under even the most rigid specifications.

2. Asphalt

The heaviest fractions of a great many crude oils include natural bitumens or asphaltenes and are generally called asphalt. Actually this material is the oldest product of petroleum ahd has been used throughout recorded history.

In 1970, a total of over 30 million short tons of asphalt products were sold in the 50 states. This represents about 153.5 million barrels or approximately 420,000 barrels per day, almost 3 percent of the total U.S. demand for petroleum products in 1970. Of the total asphalt, 78.1 percent went into paving products, 12.5 percent into roofing products, and the remaining 9.4 percent into a variety of other uses.

Since asphalt is essentially a natural product of petroleum, its characteristics vary considerably with the nature of the crude oil. Some crudes, like those found in Trinidad (natural pitch lake) or Boscan in Venezuela, produce excellent asphalts, but in general they are not available in large quantities in all the right places. Hence there have been many local asphalts with varying qualities, and at one time there were as many as 102 usuable grades of asphaltic cement. Largely through the work of the Asphalt Institute, which is the research and engineering arm of the asphalt industry, this number of grades has been cut to five.

New and expanding uses for asphalt include: road construction; the lining of reservoirs, canals, swimming pools and sewage lagoons for seepage control; the facing of dams and river banks for erosion control; and the construction of asphalt-stabilized breakwaters, seawalls, groins, etc., for the control of sea currents. Very promising results have also been obtained in the use of asphalt in soil stabilization, as a moisture barrier in sandy soil, and as asphalt concrete for railroad beds.

Asphalt products are also used for roofing and other waterproofing services and can be modified in quality for this use by air blowing. Blowing hot asphalt with air alters the relationship between the hardness at a given temperature and the softening point. Thus the temperature at which the material becomes too soft and tacky can be raised, making the material more suitable for many services.

To meet the increased demand for asphalt, the industry has increased capacity by installing additional seasonal tankage, and adjusting crude runs and providing additional plant yield by installing in-line blending and solvent-extraction facilities. Special barges and tankers have also been constructed for economical long-distance transportation facilities to ease the local shortage situations.

In-line blending has been developed by the refiner to permit an asphalt and a solvent to be drawn from their respective storage tanks and to be correctly and rapidly blended to the desired material on the way to the waiting tank car or tank truck for shipment to the place of use. This has enabled the refiner to reduce the number of storage tanks and lower his operating costs. It helps the purchaser because there is no delay in making up his desired blend, or in heating and pumping out his particular material.

Section 3.
THE MANAGEMENT OF CHANGE

In manufacturing and marketing new products for the public needs over the years, just as in other industry operations, the oil and gas industries have gathered a vast amount of experience in the factors affecting efficient management of the wide variety of changes required to meet those needs. The factors which bear particularly on the management of adjustments to meet required standards of environmental quality are not new or unique. However, they merit review and thorough consideration before decisions as to required standards and their implementation are made. In this report, the following general points are important.

- Individual operators in any industry are motivated to develop their own business programs or plans not only by existing government policies and regulations at any point in time, but also by what they anticipate will be the future government policies and regulations. Accordingly, the cause/effect relationship in national energy and environmental conservation matters must be anticipated by government policy-makers.

- In determining reasonable standards of environmental quality that are to be maintained and, where remedial action is required, the period of time within which those standards are to be reached, government should carefully take into account the cost-benefit factors and their impact upon the economy.

- There is an inevitable period of time involved in planning, financing and implementing measures and, in a number of instances, for developing the necessary technology to comply with prescribed environmental standards. Thus it is essential that realistic and stable timetables be set for achievement of the desired quality and, after standards are determined and the time period fixed for compliance, that industry be able to rely upon the resulting schedule and not be subjected to continual schedule revisions.

- Emergency actions are inherently expensive and should be avoided where possible. They may require reschedulings, equipment adjustments, new construction, dislocation of personnel and equipment, expensive borrowing of capital, and many other financial and operating actions which must inevitably be reflected in the cost of doing business. Thus, economic factors always come to bear on both the industry and the consumer, with the free-enterprise system permitting the forces of competition to ensure that the necessary products are provided to the consumer at the least cost.

- In some instances, technological advances may reach such a stage of development that they appear available for application in the very near future. If there is strong reason for confidence that such imminent technological advances will help to achieve pollution control objectives at lower cost, then such technology should be awaited, provided this is in the general public interest.

- To attempt to specify the particular method by which workable standards are to be achieved usually materially lessens the likelihood that the best solutions for society will be reached. By limiting its controls to specification of performance standards, government will encourage individual innovation, with "marketplace regulation," and thus tend to obtain the optimum environmental quality control for each dollar of investment or other expenditure, yet avoiding governmental discriminations among competing enterprises. Such an approach will maintain the benefits of a traditionally free-enterprise approach.

- Industrial research into the ways and means of controlling pollution from motor vehicles has thus laid the foundation for past significant progress and can continue to do so in the future.

- Our antitrust laws play a strong role in maintaining competition and diversity of effort. They properly prohibit conspiracy or collusive action by competitors in matters affecting commerce and public economic interests. However, to achieve the goal of improving the environment, in a number of situations it may be that the best interests of society would be served if competitors or complementary industries were permitted to exchange information regarding the modification of products or procedures in the public interest.

- As a general matter, genuine societal problems affecting the public welfare should be approached directly by the public and its government and not through indirect avenues such as governmentally imposed economic penalties.

- The long-term stability of petroleum supplies to meet the Nation's diverse needs appears to be a policy objective of the Federal Government. To achieve this desirable goal, it then becomes imperative that the Government adopt wise, firm, predictable and consistent long-range policies for environmental quality that are consistent with this objective.

A. Research for Progress

To attain environmental conservation on the most economical and effective basis, cooperation among government, industry and private citizen groups, within legal requirements, is essential. Such cooperation has been increasingly evident in recent years and has provided a valuable aid to achievement of further progress through expansion of such efforts.

Petroleum industry research, on both a cooperative and an individual company basis, has contributed to a better understanding of atmospheric chemistry and to progress in the development of technology for controlling emissions from both mobile and stationary sources. The cooperative aspects of this research effort have been carried out in a variety of ways.

Within the framework of the antitrust laws, cooperative research by the petroleum industry will continue in the future with related industries and government. Major specific needs for such further research include--

- Environmental effects of emissions into the atmosphere
- Fuel-vehicle system to produce a "pollution-free car"
- Desulfurization of fuels and stack gases.

1. Industry Association Research

Pioneering research in air pollution was begun under the sponsorship of the American Petroleum Institute in 1953. Early research demonstrated that hydrocarbons and organic matter in the air react with oxides of nitrogen in sunlight to produce photochemical smog of the type found in the Los Angeles basin. Other early studies involved photochemical reactions with sulfur oxides, measurement of ozone and other oxidants in the atmosphere, eye irritation and its relation to engine-exhaust gases, and the development of gas chromatographic methods for engine-exhaust analyses.

Later studies covered a variety of subjects, such as effects of smog on plant growth, gasoline evaporation from motor vehicles, fuel-oil combustion processes, and aerosol formation in smog. API also initiated diesel exhaust-odor studies, atmospheric lead contamination studies, and the analysis of catalytic exhaust control devices.

In 1966 and subsequent years, the research program was substantially expanded and aimed toward resolving questions in the engineering, scientific and environmental health aspects of sulfur content of heavy fuels, lead levels in motor fuels, volatility and light hydrocarbon characteristics of gasoline, and related subjects.

Indicative of the variety and scope of these continuing efforts are--

- Five volatility projects sponsored jointly with the Automobile Manufacturers Association through the Coordinating Research Council in 1967
- A study of the chemical composition and physical characteristics of power plant emissions under a wide variety of coal and residual oil combustion conditions, cooperative project with Public Health Service, Edison Electric, and Bituminous Coal Research, initiated in 1968

- A survey of existing fuel front-end compositions to provide needed information upon which to base judgments regarding alterations of volatility and/or reactivity for control of evaporation losses, funded in 1969
- A determination of whether mixing flue gas with combustion air will reduce the emission of nitrogen oxides and smoke when using residual fuel just as it does when burning distillate fuel, funded in 1970.

These activities have resulted in a closer liaison between the petroleum industry and government legislative and regulatory bodies and have supplied the industry with fundamental technical information on air pollution. Much of this information has also been helpful to government bodies, in developing workable laws and regulations directed to air pollution abatement.

2. The Coordinating Research Council

a) Organization

An outstanding example of an organization created as a vehicle for cooperation is CRC, which provides an effective forum for the various segments of the automotive and petroleum industries to work together in noncompetitive problem areas. The Council is jointly financed and administered by API and the Society of Automotive Engineers. As a result of the many CRC projects undertaken over the years, knowledge of the mutual adaptation of fuels and lubricants, with the equipment (aviation, diesel, motor) in which they are used, has advanced to a high level of proficiency and flexibility.

The organizational structure of CRC is designed to afford a straightforward method for accepting problems, developing the necessary technical information and research test techniques for their solution, and distributing the results to those interested as expeditiously as possible. To ensure that work on each project is progressing towards its assigned objective, technical committees supervise the activities within their respective fields. Each year the work of the technical committees is reported to the American Petroleum Institute, Automobile Manufacturers Association, Aerospace Industries Association, and Compression Ignition Engine Advisory Committee.

After the technical merits of a proposed project have been established by the appropriate technical committee, the CRC Industry Committee determines whether the activity lies within the CRC scope and if it will receive the necessary support in funds and personnel from the cooperating equipment and petroleum industries. Increasingly, CRC is devoting its attention to matters of environmental conservation and pollution control.

b) Work on Atmospheric Pollution

To obtain the answers and arrive at a clearer understanding of the contribution of vehicle emissions to atmospheric pollution, CRC, through its Air Pollution Research Advisory Committee (APRAC), has implemented a multimillion-dollar research program covering the engineering, atmospheric and medical aspects of air pollution attributable to vehicle sources. This program, initiated in 1968, covers a 3-year period* at a direct cost of over $12 million, and is being accomplished as a joint industry/government effort involving the participation and support of the American Petroleum Institute, the Automobile Manufacturers Association and the Air Pollution Control Office of the Environmental Protection Agency. The Automobile Manufacturers Association and the American

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*It should be pointed out that it is planned to extend the research programs for at least another 3 years beyond the original 3-year period.

Petroleum Institute participate equally in the funding of the program. The federal Environmental Protection Agency provides government funds on a selective basis and is financially supporting a majority of the projects. EPA personnel participate in all projects.

Panels of experts in all phases of chemistry, engineering, medicine, ecology, atmospheric physics and public health are directing this research effort through the CRC's Air Pollution Research Advisory Committee. The panels of technical experts design individual research projects, suggest contractors for them, monitor the research projects under way and review results. The research program is being carried out at various universities, government laboratories and private research organizations. The results of this work are all public information.

Nineteen projects have been established to investigate the engineering aspects of air pollution. These include studies related to gasoline additives; the use of leaded fuels; fuel volatility; driver habits and traffic patterns; auto-engine time-temperature surveys; diesel exhaust odors; combustion processes within engine-exhaust systems; exhaust-gas oxygenate content and exhaust-gas particulate matter; polynuclear aromatic content; and inspection, maintenance and surveillance techniques for minimizing exhaust emissions.

Seven projects have been established to deal with basic questions about atmospheric chemistry. These include studies of hydrocarbon reactivity, plant damage, diffusion of pollutants in the urban atmosphere, the fate of carbon monoxide in the atmosphere, light hydrocarbons in the atmosphere, and a literature review on atmospheric haze.

Thirteen CRC projects dealing with medical aspects of air pollution have been established, including: a survey of current knowledge regarding the effects of low levels of carbon monoxide on human performance (now concluded), an experimental medical study to assess effects of chronic exposure to low levels of carbon monoxide on human functions, studies of chronic exposure to low levels of carbon monoxide on the cardiovascular system of dogs, a study designed to lead to an assessment of carboxyhemoglobin levels in the population of the United States, a study on the toxicity of polynuclear aromatic hydrocarbons, a study on the synergistic effects of air pollutants, and the design of a research plan for investigating the effects of high concentrations of nitrogen oxides and oxidants upon human health in urban areas.

A number of programs, being conducted in laboratories of individual petroleum and automobile companies, are devoted to the development of research techniques and measurement methods for diesel exhaust emissions, exhaust sampling analysis, evaporation losses and vehicle emissions. Results of these studies will be made available to the general public.

Some of the foregoing projects were completed in whole or in part in 1969, and further progress reports and final reports are expected by 1972.

3. Inter-Industry Sponsored Programs

In addition and complementary to the type of broad formal cooperation carried out by CRC, various companies in different industry sectors have developed coordinated investigations of the problems of atmospheric pollution.

The Inter-Industry Emission Control (IIEC) program was formed by a major motor company and a prominent oil corporation in April 1967, and now is comprised of the two companies plus nine others. These companies are conducting a multi-million-dollar research program to eliminate objectionable levels of automotive emissions. Oil company members utilize their fuel and lubricant know-how, while vehicle manufacturers concentrate on development of new "hardware." This coordinated attack on a problem common to both industries is in addition to the extensive in-house programs that each of the participating companies continues to maintain.

The IIEC objectives--prior to enactment of the 1970 Clean Air Amendments--were to achieve automotive emissions levels no higher than 65 parts per million of hydrocarbons, 0.3-percent carbon monoxide and 175 parts per million of nitrogen oxides, as shown in Table 43. Currently the IIEC goals are the attainment of the 1975-1976 federal standards.

Four concept packages were developed as the result of information gathered from 18 projects carried on by IIEC. These projects range from extensive formulation and testing of catalytic agents to the construction of mathematical models of internal-combustion engine operation and chemical reactions within thermal and catalytic converters. In several instances, IIEC research efforts have accumulated new basic knowledge about the combustion process, the chemical nature of catalytic reactions, the effects of introduced air on hydrocarbon and carbon monoxide control, and the chemical interaction of hydrocarbons and nitrogen oxides in exhaust gases.

A portion of the IIEC program already has moved out of the research phase into the developmental and test-work phase. Early activities were to organize and staff the program, set out basic objectives, delegate project assignments, and conduct extensive research and development work. Now, the test track is replacing the test tube. Hardware is being evaluated, data compiled, and projects added or deemphasized. Research-developed hardware is being installed into specially built test vehicles.

In July 1967, representatives of two other well-known automotive and oil companies joined technical forces in a major coordinated effort to develop low-level emissions control systems for gasoline-powered vehicles compatible with good driving performance at reasonable cost.

The research program encompasses basic engine combustion research, engine modifications to improve combustion, fuel-evaporation control systems, balanced fuels to minimize engine deposits, specially modified lubricants, recirculation of exhaust gases to decrease nitrogen oxides, thermal and catalytic reactors to promote more complete combustion, medical research to determine the effects of atmospheric pollution, atmospheric chemistry to understand the reactions among pollutants, and analytical techniques for extremely low emissions levels.

Significant progress has been made in demonstrating the feasibility of reducing the emissions of hydrocarbons, carbon monoxide and nitrogen oxides in the exhaust gases of automotive vehicles to very low levels in this program. Future studies on gasolines and lubricants will be aimed at maintaining the efficacy of control hardware and defining the atmospheric end-effects of gasoline components.

An example of the fruits of such cooperative efforts is a workable system for virtually eliminating the evaporation of hydrocarbons. The system involves a canister of activated charcoal that absorbs evaporative emissions from the carburetor and fuel tank and releases them through special valves under controlled conditions to be burned in the engine. A system of this type is used on 1970 model cars sold in California and is being installed on all model cars sold nationwide from 1971 on. In addition to virtually eliminating evaporative losses, it has been shown to be a dependable and durable system.

4. Company-Sponsored Research

In any highly competitive industry such as the oil and gas industry, individual, competing companies carry on intensive programs of research and development to improve products and operations.

Investments by the petroleum industry for conservation of the environment already have been substantial and will undoubtedly increase in the future. In addition to capital expenditures, there have been increased expenditures for research and development.

TABLE 43

EMISSIONS REQUIREMENTS--PASSENGER CAR AND LIGHT TRUCK
(Under 6,000 Pounds GVW)

Emission	Pre-1966 (Typical)	1966 Calif.	1968 U.S.	1970		1971		1972-73		1974 Calif.	1975 U.S.*	IIEC Goals
				Calif.	U.S.	Calif.	U.S.	Calif.	U.S.			
Hydrocarbons												
gm/mi.	13-16†	*3.2*‡	*3.2*	2.2		2.2		1.5	2.2	1.5	0.5	*0.82*
ppm	*1,000-1,300*	275	275	*80*		*180*		*120*	*180*	*120*	*50*	65
Carbon Monoxide												
gm/mi.	83-90	*33*	*33*	23.0		23.0		23.0		23.0	11.0	*7.1*
% vol.	*3.5-4.5*	1.5	1.5	*1.0*		*1.0*		*1.0*		*1.0*	*0.5*	0.3
Nitrogen Oxides												
gm/mi.	3.5-7.0	NR§	NR	NR		4.0	NR	3.0	3.0‖	1.3	0.90	*0.68*
ppm	*1,000-2,000*	--	--	--		*1,200*	--	*900*	*900*	*350*	*225*	175
Particulates												
gm/mi.	0.3	NR	NR	NR		NR		NR		NR	0.10	--
Evaporation												
gm/test	60	NR	NR	6.0	NR	6.0		6.0		6.0#	?	Nil
gm/mi.	*3.9*	--	--	*0.4*		*0.4*		*0.4*		*0.4*	--	--

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* Proposed.

† Standard in regular type.

‡ Approximate equivalent in italics.

§ No Requirement.

‖ 1973 Proposed.

\# Shed Method.

While overall research and development expenditures of the petroleum industry for air and water pollution control increased 60 percent between 1966 and 1970, expenditures for air conservation increased 136 percent over the 4 years (see Figure 4, p. 28). The vehicle-emissions research portion of these expenditures increased by more than 152 percent. It is estimated that over one-third of oil company 1970 research and development dollars were devoted to sulfur oxides research.

Particularly noteworthy is the fact that a few years ago oil companies embarked on intensive research and development efforts to find ways of removing sulfur from residual fuel oil and that these desulfurization efforts have been technically successful.

B. Controlling Emissions from Mobile Sources

Of current major concern regarding atmospheric quality is control of air pollution caused by emissions of gases and particulates from mobile sources--automobiles, trucks and buses, off-highway equipment and aircraft. As indicated earlier, the petroleum industry has made extensive investigations of this subject, and major progress has already been made in its control.

The effect of motor-fuel composition on air pollution cannot be discussed meaningfully as an isolated proposition. The interrelationships between variables in vehicle design and fuel composition, as they affect emissions, are highly complex and to be treated effectively must be approached as a total system. However, given sufficient time for planning and development, fuel manufacturers can be expected to compete to supply any new market that develops for modified fuels as a result of new engine specifications and requirements. The objective should be to achieve the optimum combination of all the variables to produce the greatest degree of pollution control per unit of additional cost.

It is a fundamental responsibility of government, after consultation with the private sector, to determine reasonable standards of emissions that are to be maintained and, where remedial action is required, the period of time within which those standards are to be reached. In determining such standards and the time period required to reach them, government should carefully take into account the cost-benefit factor and its impact upon the economy.

If government limits its role to prescribing performance, the record shows that individual manufacturers will compete to achieve that performance at minimum cost. If it proves technically impossible, or too expensive, to meet performance standards without a change in fuel composition, that fact will become apparent to the technical community.

Today's newer cars emit less than one-third of the hydrocarbons and carbon monoxide emitted by the essentially uncontrolled models of the early 1960's, and the 1971 models control at least 80 percent of all hydrocarbon emissions. Even further control of all objectionable emissions is scheduled for the future. However, experience has indicated that to ensure that devices in the hands of the general public will provide the expected performance, both initially and after the car ages, education and perhaps other measures may be needed to ensure use of proper fuel and periodic maintenance checks.

These, then, are the general factors which have been proved over the years to have a strong bearing on the efficient and economical management of change in technical products and have particular application to the control of undesirable emissions to the atmosphere from the use of petroleum fuels by mobile sources. These points can be illustrated by review of known and estimated effects on some specific proposals under consideration.

1. Hydrocarbon Composition

There have been proposals to change the hydrocarbon composition of gasoline so as to reduce its front-end volatility or change its aromatic or olefinic content. The technical merits and disadvantages of this approach and others are analyzed in the following chapter, but there are other important and perhaps decisive factors which must be taken into account before a commitment is made on such proposals.

In this regard, an economic study made by Bonner & Moore Associates, Inc., on changing gasoline volatility and on replacing light olefins with paraffins determined incremental manufacturing costs and additional plant investments for average U.S. refineries. The base case for these studies was an average 1965 gasoline with a volatility of 10 RVP. The economic factors used were also based on 1965 economic conditions. The absolute incremental costs determined in that study, of course, do not reflect current economic conditions. However, the results are indicative of the relative costs for changing gasoline properties. The average U.S. incremental manufacturing cost for reducing the volatility from 10 to 7 RVP was about three times the cost for replacing the C_5 and lighter olefins in the base fuel. The additional investment required for U.S. refineries to reduce the volatility from 10 to 7 RVP was about 170 percent of the additional investment for replacing C_5 and lighter olefins.[301]

When these economic conclusions are taken together with the technical evaluations described in the following chapter, it becomes apparent that, for leaded gasolines, a change in volatility would be inordinately expensive and would have no significant benefit on total vehicle hydrocarbon emissions that can be related to photochemical smog. Furthermore, replacement of C_4-C_5 olefins provides greater reduction in reactive hydrocarbon emissions than a volatility reduction at substantially less cost. Removal of light olefins from unleaded gasolines poses substantial octane-reduction and economic problems which have not been studied extensively.

2. Lead in Gasoline

In recent months the pros and cons of elimination or reduction of lead in gasoline have been in the forefront of industry, government and public attention. Because lead antiknock usage is intimately bound up in the design, operation and economics of modern gasoline refineries, any change in the allowable concentration of lead will have far-reaching effects on the petroleum industry.

Many estimates have been made of the cost to remove lead. Reports of increased refinery investment required range from $2 to $10 billion with an attendant increase in gasoline cost of 1 to 6 cents per gallon. These cost estimates, however, refer to a hypothetical case based on the immediate removal of all lead from gasoline and the maintenance of present octane levels.[302]

However, the problem is not entirely one of capital resources and consumer cost. The physical problems of material and labor supplies for conversion of the entire industry to the production of unleaded gasoline must be considered, as must the time required for construction of new facilities. In addition, producing a given quantity of unleaded gasoline requires the use of more crude oil than the same quantity of leaded gasoline of the same octane rating. The additional drain on the Nation's crude resources would have to be taken into account.

Certainly it would be imperative that any necessary movement toward the elimination of lead from gasoline be planned realistically over a period of time. In this way the interests of the public can be served while still maintaining a practical view of what is possible for both the petroleum and automobile industries to accomplish.

The development of an optimum solution to the problem--a solution that would protect the interests of both industry and the public--might require a substantial measure of cooperation between petroleum refiners and automobile manufacturers. Where a cooperative approach would serve the public interest, the Executive Branch should clarify the extent of cooperation that is consistent with the intent of present antitrust laws and, if necessary, seek enactment of such further legislation as would be advisable to authorize the most effective means of dealing with such problems.

It is essential that any timetable established for solving the complicated problem of auto emissions be reasonable and practicable--both from the standpoint of automotive hardware and fuel composition. It seems, at the moment, most likely that such progress can be made with the active cooperation of the Federal Government in relaxing some of the restrictions which now prevent free cooperation between the two industries, and in sponsoring and encouraging work toward a joint solution.

3. Other Petroleum Motor Fuels

Recently the utility of methane, propane and butane as possible alternative fuels to gasoline has received increasing attention on the basis of their performance and emission characteristics. Propane and butane, and mixtures thereof, are referred to as liquefied petroleum gas (LPG). The technical performance and emission characteristics are reviewed in the following chapter. As with other fuels, however, the final decision with respect to the relative utility of these fuels must take into account many other factors.

There are economic factors that have held back wider application of LPG and compressed natural gas (CNG) in vehicles. First, the additional cost of the vehicle fuel system for a gaseous fuel is a significant factor. Converting a gasoline-powered vehicle to LPG costs on the order of $250 to $300; conversion to CNG involves about $350 to $400. While the above costs are high by virtue of being field conversions, factory installations (exclusive of the required and more expensive pressure vessels) for the gaseous fuels would approach field conversion costs. The second unfavorable economic factor for vehicle application of light hydrocarbon fuels is a motor fuel tax based upon ¢/gallon without regard to the energy content per gallon of the fuel. For example, the heat of combustion per gallon for LPG is about two-thirds the heat of combustion per gallon for gasoline. A tax rate of two-thirds the gasoline rate would change the tax basis to energy content.

The current U.S. production of LPG is about 20 percent of the gasoline production, and domestic supplies of LPG are not presently available to support conversion of a large portion of the current vehicles to this fuel. However, given economic incentive and time, adequate supplies of both LPG and methane could be made available from either domestic or foreign sources to meet a motor-fuel market for such products for urban fleet use in critical smog areas.

The techniques of liquefying natural gas and shipping LNG have been developed, but their further utilization requires capital-intensive projects. Similarly, propane supplies will be expanded as natural gas demand expands, since propane is derived from natural gas liquids (NGL) extraction plants and from petroleum refining operations. Also, some markets now using propane can and will switch to alternative feedstocks. For example, such alternative feedstocks could replace the 25 percent of present LPG supplies now earmarked for ethylene-propylene manufacture, given the proper economic climate. In addition, vast amounts of LPG are not presently being recovered or are being re-injected into oil reservoirs in the Middle East, Venezuela, North Africa and other rapidly emerging oil-producing areas.

Either methane or LPG could provide substantial benefits to the urban vehicle pollution problem. Supplies of either fuel could be expanded sufficiently to handle the commercial urban fleets which are adaptable to refueling from centrally located service centers required for a pressure fuel. However, these particular vehicle fleets are most concerned with operating costs and are not likely to elect to use either methane or LPG in preference to gasoline as long as the light hydrocarbons have a tax penalty. The lower vehicle conversion cost, and availability of product that could be put directly into a vehicle without further compression, favors LPG motor fuel over CNG. In some cases, safety considerations may limit use of these fuels for vehicles.

C. Controlling Emissions from Fixed Sources

1. Cost Effectiveness

A recent book, *The Economics of Air Pollution*, states that the basic air pollution abatement problem from an economic point of view is as follows: "[T]o reach a given pollution level by the least costly combination of means available; the level of pollution should be achieved at which the cost of a further reduction would exceed the benefits.[303]

Some of the control techniques to abate pollution apply to only one pollutant, while other techniques tend to reduce several air pollutants. In any case, however, there is a cost-benefit factor which must be taken into account. Discussions of costs are found in HEW publications 999-AP-40, AP-51 and AP-52. Neglecting cost-benefit considerations in control measures may lead to restrictive legislation that has the effect of diverting financial resources from other pressing needs.

Some legislation has also posed technical problems for which there are no practical solutions. The following are examples:

- Control and measurement of submicron-sized particles
- Control of organic vapors emitted at levels too low for economic recovery or combustion
- Control of odors from sulfur compounds or other substances from plants employing the "best technology" available.

Other regulatory policies permit the use of high-sulfur solid fuels and restrict use of liquid fuels to low sulfur contents. This type of legislation is in effect lowering the amount of sulfur dioxide emitted; however, it is attacking a relatively *small* source of sulfur dioxide and completely neglecting the *larger* source. Discriminatory legislation of this type is actually encouraging the use of a high-sulfur fuel.

The timetable for control of stationary sources of air pollution is in the process of being established. Once named, each air quality control region must come up with regulations that will provide the desired air quality within a certain period of time. Therefore, stationary sources will come under increased scrutiny in the next several years. Since motor vehicle emissions comprise a large percentage of the total air pollutants, they have been overshadowing emissions from stationary sources. However, with the advent of air quality criteria imposed in the air quality control regions throughout the Nation, stationary sources may have to employ control techniques to meet regional air-quality regulations.

Before much money is spent, industry, government and the public must be brought to realize that compromises will have to be made and the cost ultimately shared by all, and that, in a competitive market, the burden of extreme pollution abatement on some companies may not be economically bearable. Abatement programs must take these factors into consideration.

2. Sulfur in Fuels

It is beyond the scope of this report to attempt to provide exhaustive cost-benefit analyses of the wide variety of technical options which can be utilized or developed, given time, for the control of emissions from stationary sources. However, the following examples are provided to illustrate the effects of decisions made to lower the sulfur content of petroleum products and to take other measures with resultant benefits to environmental quality.

The petroleum industry has made substantial progress in lowering the sulfur content of its products. Given adequate lead time, reasonable fuel-sulfur regulations can be met, but this will entail some additional cost to the consumer.

A survey of expenditures for fuels desulfurization and the resulting trends in product sulfur levels was conducted by API in 1966. The results were summarized at the 60th Annual Meeting of the Air Pollution Control Association. Reported investments by domestic refiners for reducing the sulfur content of fuel products through 1965 amounted to $582.6 million. Reported capital investments by domestic natural gas processors for sulfur removal and conversion amounted to $103.6 million. In order to operate sulfur removal and conversion facilities, refiners and natural gas processors were spending about $167 million per year. Expenditures for research and development of fuels desulfurization processes exceeded $123 million through 1965 and were continuing at the rate of about $11.8 million per year.[304] In the absence of more recent data, it is assumed that both annual investments for fuels desulfurization equipment and research expenditures have continued at about the 1966 rate or higher.

The technology and cost of lowering sulfur in heavy fuel oil from Caribbean refineries was investigated by Bechtel Corporation in 1967, under contract to API. Fourteen processing schemes which reduced the sulfur content from 2.6 weight percent down to 0.5 weight percent were studied. Costs for 1.0 weight percent sulfur fuel oil were found to be approximately 72 cents on a BTU equivalent barrel and 97 cents for 0.5 percent.[305]

Costs of desulfurizing residual oil to the 1-percent level vary from approximately 25 cents to 75 cents per barrel.[306] A typical Venezuelan residual oil containing 2.6-percent sulfur would cost about 60 cents per barrel to lower the sulfur content to 1 percent.[307] These cost figures depend on a number of factors such as crude price; product demand and price; size of process; cost of raw materials such as hydrogen; import restrictions; transportation costs; value of other refinery products, including the recovered sulfur; investment payouts; and desired profits. Figure 81 illustrates the cost of desulfurization to low-sulfur levels.

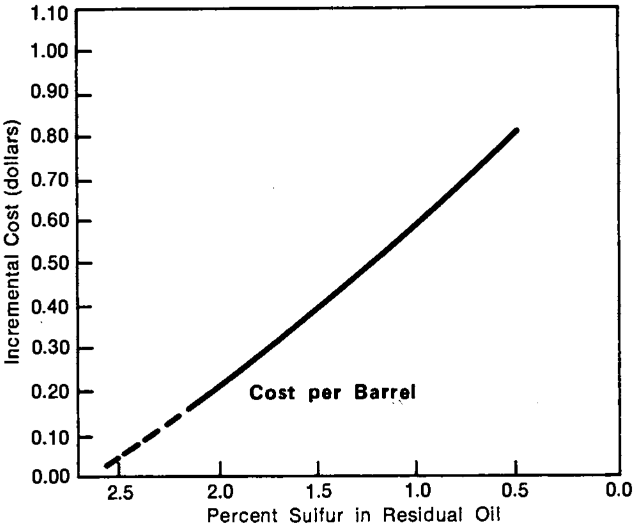
Although the Bechtel study was concerned specifically with heavy fuel oil from Caribbean refineries, somewhat comparable costs would be incurred by domestic refiners, since the processing options which might be considered would be the same.

Other approaches to control of air pollution from sulfur oxides include fuel substitution or the utilization of new energy systems.

Most studies have defined the cost of fuel substitution as the difference between current fuel expenditures and the expenditures required to obtain low-sulfur fuels providing the same net heat input.[308] Fuel substitution may involve additional costs for transportation, fuel price, storage and handling, burner replacement, and combustion chamber modifications. An HEW Control Techniques Manual describes procedures used to determine fuel substitution costs in a specific geographic area.[309]

In 1969, fossil-fueled power plants produced over 82 percent of the electricity generated in the United States. Discharges from these plants contributed about 50 percent of the sulfur oxides, 25 percent of the particulates, and 25 percent or less of the nitrogen oxide emissions.

Thus, the impact of air pollution control on stationary sources, such as electric power generation, will be immensely increased over the next 10 to 20 years, as the demand for this type of energy escalates. Frequently, however, it is believed that relief may be in sight if nuclear power can be utilized instead of fossil fuels. This source alone is not the single answer, though, since nuclear power plants are not free of either air or thermal pollution potential. Instead, emphasis must also be placed on the development of new energy systems. These systems include requirements to improve both methods for transmission of energy and methods for conversion of energy. Consequently, the new energy systems will depend on the economic optimization of new developments in transportation and in conversion of energy. In particular, this optimization is exceedingly essential to solve problems relating to new sites for power generation. Although raw materials transportation costs may be minimized by con-



Source: "Desulfurization Costs (for) Residual Fuel Oil - - Typical Caribbean Refinery - - Venezuelan Crude Oil" (Bechtel Corp., February 1967).

Figure 81. Incremental Desulfurization Costs Per Barrel

structing generation facilities at a mine mouth, the cost of electrical transmission from this point can in many cases offset the raw materials transportation savings. An alternative to select a site to optimize both the transportation of the raw material and the finished product, i.e., electricity. Several options exist to accomplish this. Raw materials may be transported via unit train or via a slurry pipeline. In this case, the cost for transportation of raw materials via slurry pipeline is estimated at about 2.4 cents per million BTU's per 100 miles *versus* 2.5 cents per million BTU's via unit train.

But more important, this alternate site provides a method whereby sulfur dioxide and fly-ash disposal are still isolated from the area directly using the electricity. The second part of energy transportation costs (i.e., transmission) must be included in arriving at the overall cost for the energy transportation from mine mouth to consumer. Again alternatives are available, but before discussing these, one other form of raw materials movement should be considered.

This alternative is available via coal gasification. In this case, a solid and its potential sulfur dioxide and fly-ash problems are left behind and an intermediate product, gas, is transported and used to generate electricity.

For the case of bituminous coal, gas prices of 50 to 52 cents per thousand standard cubic feet are estimated based on a 250-million-standard-cubic-feet-per-day gasification plant operating at 90-percent stream efficiency.[311] Alternate transmission possibilities, although somewhat remote, include electrogasdynamics (EGD) and magnetohydrodynamics (MHD). In the case of EGD, the pressure of energy of a flowing gas is converted directly into high-voltage electricity. Charged positive ions are directed onto fly-ash particles from coal combustion gases by a means of corona discharge. The charged ash particles move to a collector electrode where they are discharged from the particles and routed to an external resistance. Current is forced through the resistance by the gas pressure exerted on the charged ash particles, whereby the particles are forced against the opposite electric field in the generator.

The advantage of the EGD potential development is that it can operate at a higher efficiency and requires less capital than a conventional electric power generation facility. There are no boilers, no condensers, no forced air fans, and less cooling requirements than required for conventional facilities. The electricity generated is produced directly at high voltage, therefore reducing the need for transformers. Costs are estimated at 3.2 mills per kilowatt hour (KWH) for EGD *versus* 4.3 to 4.5 mills per KWH from a similar-sized (500-megawatt) conventional plant.[312]

Currently an EGD system is being developed on a bench-size scale under contracts from the Office of Coal Research. Scale up to a pilot plant for additional study will be required before the process is commercialized. Therefore, it appears that it will be the mid-1980's before EGD is available on a competitive scale.

MHD is also being explored under contracts from the Office of Coal Research. In this process, the combustion products of fuel and air are made to conduct electricity by the addition of small amounts of a salt. The combustion gases then become the armature in an MHD unit where they move at very high velocity through a magnetic field. Here electric power is generated directly. Capital costs are estimated at $120 per KWH and operating costs are 4.3 mills per KWH, compared to $20 per KWH and 4.5 mills per KWH for conventional power plants.[313] The MHD process, although it promises reduction of noxious emissions from fossil-fueled plants, is also in the development stage, so it too will not be available until the mid-1980's.

Present legislation requires stringent limitations on fuel-sulfur contents. Los Angeles set a 0.5-percent sulfur maximum on heavy fuel oil; New Jersey, a 0.5-percent sulfur in October 1970 and 0.3-percent sulfur by October 1971; Philadelphia, a 1-percent sulfur maximum for 1970 and a 0.3-percent sulfur maximum for oil as well as coal in 1973. In addition, the New York City metropolitan area will require 0.37-percent sulfur in October 1971. At this writing there are, because of the general shortfall in availability of other energy fuels and a consequent sharp increase in demand for petroleum residual fuel, problems with respect to meeting low-sulfur fuel-oil requirements in certain areas within the planned time frame.

Thus, although processing equipment and technology are generally available for reducing the sulfur content of gasolines, home heating oils, diesel fuels and other distillate products to an acceptable level, improved methods of processing which will reduce the cost of lowering the sulfur content of residual fuel oil are needed.

Given adequate lead time and economic incentive, the petroleum industry could supply additional quantities of low-sulfur heavy fuel oil. The trend among domestic refiners, however, has been to install processing equipment that converts the heavy residual portion of crude oil into more valuable, lighter products, and to minimize the production of residual fuel oils. This trend is apt to continue as long as residual fuel oil continues to sell, in competition with other energy sources, at prices that do not permit recovery of raw materials and processing costs.

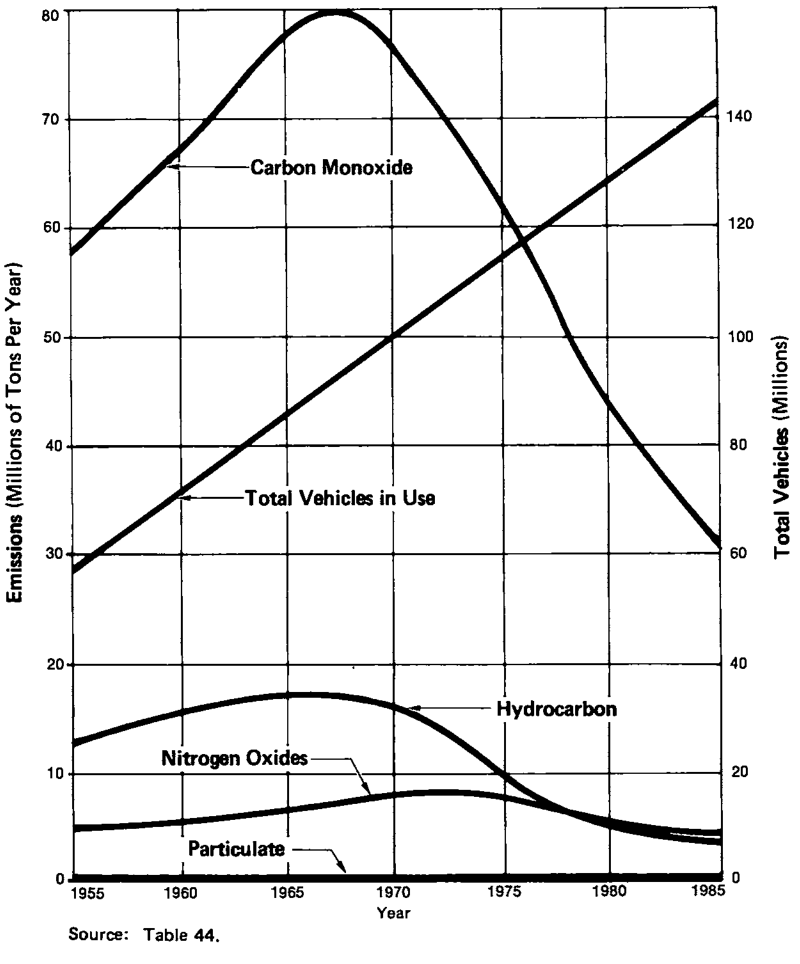
MOBILE AND OFF-HIGHWAY EQUIPMENT—EMISSIONS AND TRENDS

Emissions from engines in mobile equipment are two kinds--gaseous and particulate matter. The important gaseous emissions are--

- Hydrocarbons (also aldehydes)
- Carbon monoxide
- Nitrogen oxides.

While the standards for vehicle particulate emissions have not yet been set, proposals for such standards have been made and these are used in this study to estimate particulate emissions.

Emissions trends have been projected, prior to the enactment of the Clean Air Amendments of 1970, for a 15-year period (see Figure 82). These projections are useful for indicating general emissions trends and the relative contribution of emissions from various sources. They also provide a good basis for assessing the progress that is being made and will be made in controlling the emissions from mobile and off-highway equipment. If the standards established by the 1970 Act prove to be attainable, estimated emissions after the 1975-1976 period would be further reduced.



Source: Table 44.

Figure 82. Mobile Equipment Emissions.

Table 44 and Figure 82 provide a breakdown of estimated emissions from mobile and off-highway equipment for the period from 1955 to 1985. Further analysis of emissions from various types of mobile and off-highway equipment is contained in the sections that follow.

Emissions estimates presented in this chapter are related to the emissions standards and factors listed in Table 45 and were made on the basis of the 1968 Federal Test Procedure, before the new Federal Test Procedure incorporating the Constant Volume Test System (CVS) was published. Because the emissions levels measured by the new CVS procedure are higher than those measured by the 1968 procedure, the absolute emissions levels estimated in this study would be increased if revised to conform to the new CVS basis. Although the updated emissions estimates would be higher, the trends of the emissions estimated by the two bases would be similar and similar conclusions would be drawn.

The summary data in this report show that the trend of emissions is down from the emissions peaks which were reached in the 1965-1970 period and that by 1985 the emissions peaks are expected to be reduced approximately as follows: hydrocarbons, 80 percent; carbon monoxide, 60 percent; nitrogen oxides, 45 percent; and particulates, 40 percent.

TABLE 44

ESTIMATED EMISSIONS FROM MOBILE EQUIPMENT
(Millions of Tons per Year)

	1955	1960	1965	1970	1975	1980	1985
Hydrocarbon							
Autos	9.9	12.0	13.0	11.0	5.9	2.4	0.9
Trucks & Buses	1.2	1.4	1.7	1.9	1.7	1.4	1.4
Aircraft	.3	.3	.2	.3	.2	.1	.1
Off-Highway	.7	.7	.7	.6	.6	.6	.5
TOTAL	12.1	14.4	15.6	13.8	8.4	4.5	2.9
Carbon Monoxide							
Autos	37.3	45.7	55.2	54.3	40.6	24.3	12.7
Trucks & Buses	11.1	12.7	15.6	17.4	16.2	14.0	14.2
Aircraft	2.2	1.4	.9	.4	.5	.7	.8
Off-Highway	6.7	6.8	5.7	5.3	5.5	4.4	3.4
TOTAL	57.3	66.6	77.4	77.4	62.8	43.4	31.1
Nitrogen Oxide							
Autos	3.3	4.0	4.8	5.7	5.0	2.8	1.3
Trucks & Buses	.8	.9	1.1	1.4	1.6	1.5	1.7
Aircraft	.01	.01	.03	.05	.06	.08	.09
Off-Highway	.8	.9	.9	.9	.9	1.1	1.1
TOTAL	4.9	5.8	6.8	8.1	7.6	5.5	4.2
Particulate							
Autos	.2	.2	.2	.3	.3	.2	.1
Trucks & Buses	.1	.1	.1	.2	.2	.2	.2
Aircraft	.01	.01	.02	.04	.04	.04	.05
Off-Highway	.2	.2	.2	.2	.2	.2	.1
TOTAL	.5	.5	.5	.7	.7	.6	.5

Bases: 1968 Federal Test Procedure; Table 45, "Emissions Standards and Factors: Automobiles."

TABLE 45

EMISSIONS STANDARDS AND FACTORS: AUTOMOBILES*

	Exhaust Emissions (g/mi)										Evap. (g/Test)	
	Crankcase		Hydrocarbon		Carbon Monoxide		Nitrogen Oxides		Particulate		Hydrocarbon	
Year	Calif.	U.S.	Calif.	U.S.	Calif.	U.S.	Calif.	U.S.	Calif.	U.S.	Calif.	U.S.
†	5.9	5.9	10.6	10.6	73	73	6.4	6.4	.36	.36	2.7‡	2.7‡
1961	NIL§											
1962		NIL§										
1963	NIL‖											
1964	NIL#											
1965												
1966		NIL**	3.4††		35††		7					
1967												
1968				3.4††		35††		7				
1969												
1970			2.2	2.2	23	23					6‡‡	
1971							4					6‡‡
1972			1.5				3	4				
1973				1.5				3				
1974							1.3	1.3				
1975			.5	.5	12	12	1.0	1.0		.1		
1980				.2§§		5§§		.4§§		.03§§		
Control	100%		98%		93%		94%		92%		95%+	

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* Light-duty vehicles under 6,000 pounds.

† Uncontrolled cars.

‡ Evap. loss estimated at 2.7 g/mi.

§ Semiclosed system--new cars.

‖ Semiclosed system--used cars.

Closed system--new and used cars.

** Closed system--new cars.

†† 275 ppm HC, 1.5% CO.

‡‡ Emissions estimated at .05 g/mi.

§§ Figures released by President's Environmental Quality Council, November 20, 1969.

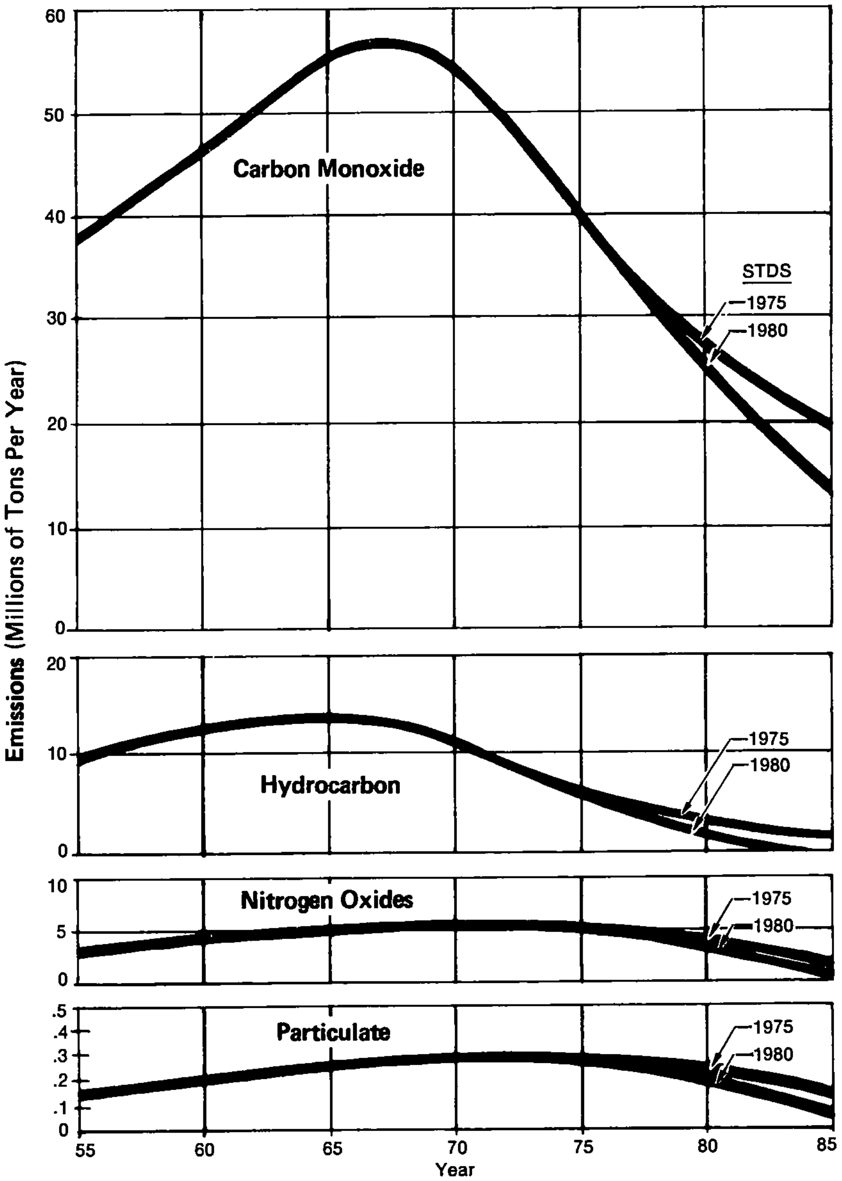
Sources: State of California Motor Vehicle Pollution Control Board, "California Procedure for Testing Motor Vehicle Exhaust Emissions" (revised March 9, 1966); 33 *Fed. Reg.* 108, Part II (June 4, 1968); *Wall Street Journal* (January 22, 1970).

The 80-percent reduction in hydrocarbon emissions and the reduction in the HC/NO_x ratio are particularly important because hydrocarbons and the HC/NO_x ratio exert an important effect on photochemical smog. The indicated reduction in hydrocarbon emissions is expected to reduce considerably the incidence of photochemical smog and the severity of its effects.

Section 1.
SOURCES OF EMISSIONS

A. Automobile Emissions

The emissions that are estimated to arise from automobiles are shown in Figure 83. The emissions standards and factors on which these estimates are based are given in Table 45. The trend of carbon monoxide and hydrocarbon emissions is expected to be sharply down in the 1970's and by the 1980-1985 period will



Source: Tables 44 and 45.

Figure 83. Automobile Emissions.

reach very low levels. Nitrogen oxides and particulates follow similar trends and will be reduced to very low levels by the end of the forecast period.

The emissions standards and factors presented in Table 45 indicate the degree to which the emissions from uncontrolled cars have been and would be reduced, not considering the Clean Air Amendments of 1970. However, technology is not now available to reduce emissions to the levels established in the 1970 Amendments for 1975-1976. If and when these standards are met, emissions for new vehicles as compared to uncontrolled cars will have been reduced as follows:

	1970 Amendments-- 1975-1976 Emissions Standards (Percent Reduction)
Crankcase	100
Hydrocarbons	98
Carbon Monoxide	97
Nitrogen Oxides	90
Particulates	90
Evaporative	95+

B. Truck and Bus Emissions

Truck and bus emissions data show that the hydrocarbon and carbon monoxide emissions from trucks and buses will trend down moderately after reaching peaks in the 1970 period, while nitrogen oxides and particulate emissions will remain essentially constant (see Table 44).

If the use of diesel engines is greater (at the expense of gasoline engines) than that assumed in this study, then these emissions estimates could prove to be high. Available information suggests that emissions from diesel engines other than smoke or odor are not much of a problem and can and will be controlled. It further suggests that smoke emissions will be eliminated.

Catalytic converters of various types may find increasing utilization on city trucks and buses in the future. It is expected that during the forecast period units will become available which will meet the needs of city truck and bus operation.

C. Aircraft Emissions

Aircraft emissions data in Table 44 show the estimated emissions produced below 3,500 feet from air carrier and general aviation operations. Redesign and retrofitting of jet engine combustors is significantly reducing the smoke problem.

Thus the total level of pollutants emitted is low compared to other mobile sources. Although emissions from aircraft may be a local annoyance, they are not projected to become a major factor in the total air pollution burden over the period covered by this survey.

D. Off-Highway Equipment Emissions

The off-highway equipment emissions data in Table 44 show that off-highway equipment emissions are not large and based on this survey are expected to become even smaller in the future.

Section 2.
FACTORS AFFECTING EMISSIONS

The possible reduction of engine and vehicle emissions by means of gasoline composition changes has been the object of considerable speculation and work since the beginning of efforts to control automotive emissions. Early work showed that gasoline modification was generally an ineffective way to reduce emissions and that the largest reduction in vehicle emissions could be achieved by changing engine and vehicle design and operating conditions. This emphasis on changing the engine and vehicle has been followed for the past decade with large reductions in emissions being realized. Now, in order to reduce emissions to the minimum possible with the gasoline engine, changes in gasoline composition and properties are being reevaluated to determine their role in making the "non-polluting" vehicle a practical reality.

The relationships between the composition of gasoline and emissions are complex and are different for different types of vehicles. For example, the composition and reactivity of exhaust emissions from uncontrolled engines are quite different from the exhaust emissions produced from engines equipped with thermal reactors.[314] Thus, in evaluating the effect of possible gasoline modifications, consideration must be given to the different kinds of engines and vehicles in which the gasoline is to be used. For some kinds of gasoline modifications this precludes broad generalizations as to emission effects.

In any case, the factors that have an important bearing on the ability to control evaporation and emissions are the volatility of the fuel, its aromatic and olefinic content, and additives.

A. Motor-Fuel Volatility

Motor fuel is principally a mixture of hydrocarbons derived from petroleum with most of the individual hydrocarbons containing 4 to 10 carbon atoms and the properties and characteristics of a blended motor fuel controlled by the amount of the various hydrocarbons in the blend, additives being included to provide specific performance benefits. One of the most critical and closely controlled properties of motor fuel related to the hydrocarbons in the blend is volatility.

Balanced volatility of the motor fuel is a term used to indicate the proper proportioning of the individual blending materials to provide a fuel that will ensure easy starting, good mileage, freedom from vapor lock and carburetor icing, fast warm-up and minimum crankcase oil dilution. The characteristics of the more volatile components are important for several performance characteristics. For example, increasing the proportion of the more volatile components in gasoline will improve ease of starting and warm-up rate but increase the possibility of vapor lock and carburetor icing. Increasing heavier components, which have a higher density, could provide better mileage and less vapor lock; however, crankcase oil dilution would increase, and starting and warm-up would be adversely affected. Therefore, a proper balance of these properties can be obtained by control of the amount of various blending components to optimize the performance characteristics of the motor fuel for seasonal changes and different geographical zones.

The 4 and 5 carbon hydrocarbons in the gasoline are largely responsible for the initial boiling point and the volatility characteristics for the front-end of the evaporation-temperature relationship for the gasoline. These hydrocarbons contain both olefinic (reactive) and paraffinic (non-reactive) materials. The relative amounts of the olefinic and paraffinic hydrocarbons are determined by the source of material and refining techniques employed. Hydrocarbons derived from naturally occurring petroleum products such as natural gasoline will be essentially all paraffinic hydrocarbons, while the hydrocarbons derived from refining operations will contain both paraffinic and olefinic components. Many of these light hydrocarbons provide high-octane and clean-burning components to the motor fuel. The normal paraffinic, light hydrocarbon materials, such as normal pentane, can be isomerized to iso-paraffins to provide a substantial increase in octane ratings of the paraffins without a significant change in the volatility properties of the motor fuel.

For satisfactory starting of a cold engine, gasoline needs to have adequate "volatility" to supply an air-fuel vapor mixture that is combustible to the spark-ignition engine. Research indicates that the mid-range volatility characteristics are more important for warm-up* performance than the light ends (the more volatile portion) or heavy ends in the fuel. The temperature for 50-percent evaporation, using the ASTM distillation procedure, is an arbitrary index of the mid-range volatility.

An important consideration related both to the volatility of a motor fuel and to the characteristics of the automobile in which it is used is vapor lock. Vapor lock occurs when fuel vaporizes in the fuel system in sufficient quantity to prevent an adequate supply of fuel from flowing to the engine. The vapor forms in the fuel system because the temperature and pressure in the fuel system cause the lighter components in the gasoline to partially vaporize. This characteristic of a given fuel is related to the temperature required to obtain a specific volume ratio of the vapor and liquid phases at equilibrium in a closed system for a given pressure. Very careful control and balance of the volatility of the motor fuels are needed to provide fuels that will perform satisfactorily in the modern automobile engine.

In addition to the important relationships of fuel volatility to engine performance, evaporation from automotive fuel systems, engine emissions and marketing losses are also affected by this characteristic. Marketing losses were discussed in "Industry Operations," Chapters Three through Seven of this report.

An extensive study conducted by the U.S. Bureau of Mines, contracted to API, developed some important data on the interrelationship of fuel volatility and total vehicle reactive emissions. It involved measuring all emissions from 16 vehicles driven over a typical Los Angeles trip cycle for a range of simulated ambient temperatures. Exhaust emissions were measured from key-on to key-off during each trip cycle.[315]

The data from this study showed that decreasing fuel volatility from 10 RVP decreases the smog-forming potential of evaporative emissions but increases the smog-forming potential of exhaust emissions. As a result, the net effect depends on the magnitude of these two balancing effects in the car population. As cars with evaporative-loss control systems increase, the effect of the increase in exhaust reactive hydrocarbons with lower volatility fuels should become more significant.

The implications of the aforementioned laboratory test work were examined in the light of actual conditions in Los Angeles during the summer months when days with photochemical smog and/or high ambient temperature occur most frequently. A joint committee representing the California Air Resources Board, Los Angeles County Air Pollution Control District and the Western Oil and Gas Association examined the net effect of using lower volatility fuels in the Los Angeles basin during the summer. The joint committee study[316] factored earlier laboratory data[317] into the marketing practices and into the driving patterns and ambient conditions unique to this location. It projected its estimates to 1972 and 1985, the latter being considered as the year when all old, unequipped vehicles will have been eliminated from the Los Angeles car population. It was concluded that a reduction in volatility of the gasoline marketed in Los Angeles County from an average of 8.6 to 6.0 RVP (with proportionate changes in front-end distillation temperatures) should produce changes of the order indicated below:

	Vehicle Emissions		
	1968	1972	1985
Net Reduction (Increase) in Reactive Organic Emissions (Tons)	(-0.1)	5	4
Reduction in Emissions from Gasoline-Associated Sources (Percent)	0.0	1.2	2.9

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*The warm-up period for an engine is defined as the running time required to provide smooth acceleration from a given speed in high gear.

Whereas it is clear from the foregoing that motor fuel volatility has no important effect on the total emission impact of vehicles without mechanical evaporative emissions controls, little data have been obtained to determine volatility/exhaust emissions interactions during the purge cycles on vehicles with these controls. Such data as has been obtained indicate that reducing gasoline volatility does not produce worthwhile reductions in vehicle emissions in customer use. Vehicles equipped with evaporative control devices exhibit volatility/exhaust emission interactions during the purge cycles. To obtain information indicating the scope of this problem, the automobile and petroleum industries are supporting a cooperative program in CRC-APRAC which involves the measurement of total vehicle emissions with several cars having the first-generation evaporative control hardware.

At various times spokesmen for the automotive industry have proposed that the volatility of gasoline be lowered to reduce the evaporative emissions of unequipped vehicles and gasoline distribution systems.[318] While these proposals correctly state the benefits to be obtained from reducing volatility, they generally underestimate the problems associated with the use of low-volatility fuels, that is--

- Loss of vehicle driveability and performance due to poor starting and slow warm-up
- Increase in total reactive emissions due to increase in specific reactivity and mass of exhaust emissions.

As described earlier, studies conducted by the Bureau of Mines showed that, in balance, reductions in volatility to the 5-RVP level increased vehicle reactive emissions rather than decreased them.[319] Other work showed that similar decreases in fuel volatility substantially increased vehicle starting and warm-up problems.[320] These vehicle driveability problems were confirmed in the Consumer Reaction Tests carried out by General Motors in the Los Angeles area. These data were presented by D. T. Wade, in his prepared discussion of a paper by E. E. Nelson reporting these tests,[321] given on behalf of API.

Another factor often overlooked in volatility-reduction proposals is that the modifications being made to engines to reduce emissions are making engines harder to start and more difficult to warm up. This serves to increase the driveability problems which were found in pre-control and first-generation control cars with low-volatility fuels. However, probably the most serious objection to decreasing volatility is that decreasing volatility means butane removal. From a combustion and an exhaust-emissions point of view, butane is the best of all gasoline hydrocarbons. It burns easily and cleanly, and all of its combustion products are simple and of low reactivity. Removing butane by reducing volatility increases the concentration of relatively less desirable hydrocarbons, thus increasing the exhaust-emissions problem.

B. Olefinic and Aromatic Content

It has been well established that all hydrocarbons do not participate at the same rate and to the same extent in atmospheric photochemical reactions, nor do they produce photochemical products which are equally objectionable. For example, most authorities now agree that C_1 to C_5 paraffins, acetylenes and benzene are not significant contributors to the phenomenon known as photochemical smog.[322] Most of the other hydrocarbons found in vehicle exhaust and evaporative emissions have now been catalogued with respect to their tendency to participate in photochemical reactions, but not all have been investigated with respect to the effects which can be produced by their photochemical-reaction products. Thus, while a variety of hydrocarbon photochemical-reactivity scales exist[322] and it is possible to use them to indicate the relative tendencies of hydrocarbons to participate in atmospheric reaction,[324] it is not possible to assess the total environmental effects of these hydrocarbons by these scales. Consequently, a complete assessment of the contribution to air pollution from automobile evaporative and exhaust emissions should include not only both the quantity and reactivity of the individual emissions, but also a consideration of effects such as health, visibility reduction, etc., which are not covered by these scales. In any case, studies of the possible effects of gasoline modifications on photochemical smog and environmental effects must be conducted with extreme care, giving due consideration to all of the factors.

The situation outlined above had been recognized early in the study of the Los Angeles smog problem and led to the limitation on the amount of total olefins permitted in Los Angeles-basin gasoline and to restrictions on the composition of industrial organic solvents used in that area. Whereas it is generally accepted now that the composition of vehicle-exhaust hydrocarbon emissions is more a function of the vehicle operating conditions than the type of hydrocarbons in gasoline, it is obvious that the composition of evaporative hydrocarbon emissions is directly related to the composition of the lighter-boiling hydrocarbons in gasoline. Since the chemical composition of the front end of gasoline can be changed without materially affecting the physical properties of the gasoline, which in turn could affect the quantity of exhaust emissions, the petroleum industry has made some very careful studies of the benefits of gasoline front-end composition changes on automobile-induced pollution. Since evaporative emissions are primarily C_5 and lighter hydrocarbons, emphasis has been given to studies of the benefit of substituting C_4 and C_5 paraffins for C_4 and C_5 olefins in gasoline. These studies were sponsored by the API. Each project has been guided by a small committee of technical experts selected by the various petroleum companies who formulated the program objectives. The studies cited herein are applicable to tested fuels only.

Reference has already been made in the previous discussion of volatility to a general study conducted by the Bureau of Mines, which also related the effect of reducing the light olefins in gasoline to the hydrocarbon emissions.[325] The relative quantity of emissions for each of the fuels tested in this study is shown in Table 46, based on a relative value of 100 for the hydrocarbon emissions for the base fuel, which was typical of the 1965 U.S. average motor fuel then being marketed.

TABLE 46

OLEFIN REDUCTION EFFECT ON EMISSIONS

	Base Fuel	Substituting C_4 and C_5 Paraffins for C_4 and C_5 Olefins	Substituting C_4 to C_7 Paraffins for C_4 to C_7 Olefins
Nominal Vapor Pressure (RVP)	10	10	10
Relative Gross Hydrocarbon Emissions (Base Case=100)	100	101	102
Exhaust Hydrocarbon Emissions	60	61	60
Evaporative Hydrocarbon Emissions	40	40	42
Relative Reactive Hydrocarbon Emissions (Base Case=100)	100	77	71
Exhaust Reactive Hydrocarbon Emissions	62	63	62
Evaporative Reactive Hydrocarbon Emissions	38	14	9

These tabulated data show that the total mass of hydrocarbon emissions was essentially the same for the three fuels, i.e., the base fuel and two low-olefin fuels. However, a significant reduction in smog-forming potential of the total hydrocarbons occurs because of the decrease in reactive emissions. Replacement of the C_5 and lighter olefins resulted in the largest incremental reduction in total reactive hydrocarbons (23 percent), while replacing the C_7 and lighter olefins resulted in only a small additional reduction (to 29 percent) in reactive hydrocarbons. As would be expected, the reactive hydrocarbons in the exhaust are essentially equal for all three fuels, indicating that fuel composition has little effect on the exhaust smog-forming potential. The reduction was a result of a decrease in the smog-forming reactive hydrocarbons in the evaporative losses. This reduction in reactive olefins is applicable to vehicles without evaporative emissions control systems.

Later, a joint committee (mentioned earlier in the discussion of volatility) representing the California Air Resources Board, Los Angeles County Air Pollution Control District and the Western Oil and Gas Association not only examined the effect of using lower volatility fuels in the Los Angeles basin during the summer, but also examined the net effect of removing the light olefins. The joint committee study[326] factored in earlier laboratory data[327] into the driving patterns and ambient conditions unique to this location and projected its estimates to 1972 and 1985, the latter date being considered as the year when all old, unequipped vehicles will have been eliminated from the Los Angeles car population. It was concluded that replacing the C_4 and C_5 olefins from the gasoline marketed in Los Angeles County and maintaining the volatility constant should produce changes of the order indicated below:

	Vehicle Emissions		
	1968	1972	1985
Net Reductions in Reactive Organic Emissions (Tons)	37.6	30	14
Reduction in Emissions from Gasoline-Associated Sources (Percent)	6.5	7.4	10.2

These results clearly demonstrate that replacement of C_4 and C_5 olefins provides greater reduction in reactive hydrocarbon emissions than a volatility reduction (see p. 313). There are substantial economic aspects which are discussed elsewhere in the report.

The only important negative aspect of C_4-C_5 olefin saturation (replacement) is concerned with research octane-number considerations. In the case of unleaded gasolines, saturation of C_4-C_5 olefins will produce a substantial drop in the octane number of the C_4-C_5 component and in the gasoline in which the saturated component is blended. The effect of the octane reduction is minimized in the case of leaded fuels because of the excellent lead response of the C_4-C_5 saturated hydrocarbons. When this octane-number drop is considered along with the generally poor road octane performance of unleaded gasolines *vis-à-vis* leaded gasoline of the same laboratory octane number, it is evident that saturation of the C_4-C_5 olefins in unleaded gasolines will make an already difficult situation more difficult.

The olefin content of motor gasolines has been decreasing in recent years because olefins in the gasoline boiling range have found increasing utilization as charge stocks for alkylation, polymerization and hydrotreating-reforming processes. At present relatively little C_4 olefins find their way into gasolines because of these other demands; however, actual C_4 olefin content can vary from time to time and place to place because of changing demands. This means that of the light olefins that are important with respect to evaporative emissions, C_5 olefins are the most important and the C_4 and C_6-C_7 olefins are of lesser importance.

With respect to the aromatic content of gasolines, there is little incentive or need to increase aromatics above present levels unless lead is removed. Increases in the concentration of aromatics in gasoline would tend to increase the concentration of aromatics in vehicle emissions. The amount of increase in aromatic emissions would depend upon many factors and would, for a given increase in gasoline aromatics, tend to be greater in older cars than in newer cars.

Aromatics are less reactive than olefins; however, their photochemical-reaction products appear to contribute to more particulate formation, visibility reduction and eye irritation.[328] At present, information is not available to permit a comprehensive assessment of the changes in environmental effects expected to occur if gasoline aromatics are increased. Research on this problem is currently being sponsored by the API, and definitive answers to these questions are expected in the near future.

Another problem associated with gasoline aromatics is the generation and emission of polynuclear aromatics from automotive engines. Research is currently being conducted in CRC-APRAC on the emission of polynuclear aromatics in vehicle exhausts.

C. Additives--Lead Antiknocks

In recent years there has been an increased emphasis on examination of the additives used with petroleum fuels as a possible factor in atmospheric pollution. Lead in gasoline has been the primary focus of attention, with statements being made by senior government officials to the effect that lead must be eliminated from gasoline. Two states have already adopted air quality standards for lead concentration, and EPA is expected to publish criteria for allowable limits of lead for ambient air in 1971. These criteria would serve as a basis for standards to be adopted by states in air quality control regions. In the light of these and other developments, the following assessment reviews various scientific and technical aspects of reduction or removal of lead additives from gasoline as drawn from studies to date. The economic effects are assessed elsewhere in this report. Concern has been expressed about the effects of lead on the following:

- Health
- Engine emissions levels
- Control system deterioration.

1. Lead Concentrations and Health

A December 1965 HEW-sponsored "Symposium on Environmental Lead Contamination," attended by scientific and technical personnel, reported that about 10 percent of man's intake of lead comes from breathing lead in the atmosphere. The remaining 90 percent is accounted for in his food. The combustion of leaded gasoline is regarded as the "principal source" of atmospheric lead. However, the HEW symposium reported that there is "no conclusive evidence that there is an extensive problem of effects on health."[329]

Despite the fact that gasoline production and lead usage have been growing, the average concentration of airborne lead over U.S. cities does not appear to be increasing. Typical data illustrating this trend is presented in Table 47.

A similar conclusion was reached as the result of a survey conducted in the early 1960's by the Public Health Service in three major U.S. cities: Los Angeles, Cincinnati and Philadelphia. Lead levels in the atmosphere were monitored for a 5-year period, and they showed no consistent trend, either up or down. The results led to a measure of concern for the safety of workers in some specific occupations, such as garage mechanics, but did not support any fears of a threat to the general public.

TABLE 47

YEARLY AVERAGE LEAD CONCENTRATIONS
U.S. CITIES OVER 100,000 POPULATION IN NASN*

	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
Average Pb in Air, ug/m^3	2.27	1.32	0.61	0.62	0.50	1.40	0.87	1.37	0.99	0.96	0.74
Std. Dev.	1.47	1.02	0.34	0.23	0.36	--	0.53	0.95	0.81	0.42	0.32
No. Cities	12	19	14	5	24	1	6	11	28	17	20

* National Air Sampling Network.

Source: G. J. Stopps, "Petroleum and Air Quality Criteria--Lead," *Journal Occupational Medicine*, Vol. X, No. 9 (September 1968).

While these data show that the average concentrations of airborne lead over cities are not increasing, it is likely that the total area over which these concentrations are present is increasing. Thus, it is likely that greater numbers of people are being exposed to city airborne lead concentrations for longer periods of time than heretofore and that this increase in lead exposure is likely to continue to rise.

Some investigators feel that the present atmospheric lead levels are safe, while others do not share this view. So far as is known, there has been no evidence found that the current airborne lead concentration and exposure levels have produced any significant health effects in the normal population.[330] This is an important point which should not be overlooked in considering the lead question. Theories as to possible effects are not tantamount to actual health effects and at present there is no evidence of actual health effects. Those who do not believe that the present lead exposure is safe point to research which indicates that lead at the body lead concentrations found in urban dwellers does interfere with certain bodily processes. Evidence has also been advanced to indicate that the body lead burden of urban dwellers, particularly U.S. urban dwellers, is higher than non-urban dwellers and that these body lead levels hold the potential for long-term health damage.[331] These findings cannot determine what the health effects are, but they do indicate an area of concern and suggest that further studies should be made.

The position of most participants in the 1965 HEW symposium was that considerably more research would be needed before any firm conclusions could be drawn about the potential threat of lead as an atmospheric pollutant. More information was needed about both the level of lead in the atmosphere and the lead level in body fluids of people.

Research to obtain this type of data has been going on during the intervening years and is still being conducted on a wide scale, much of it financed in part by API and other interested industry associations and the Air Programs office of EPA. A seven-city survey, for example, is now under way to monitor atmospheric lead concentrations, four cities being added to the three included in the original survey. A separate study is being made of lead concentrations along heavily traveled highway routes in New Jersey. None of these studies, however, has progressed far enough to provide accurate, significant data on the total problem.

Table 48, following, shows the consumption of lead antiknocks together with gasoline sales for the period back to 1955 and extrapolated forward to 1985.

TABLE 48

U.S. GASOLINE AND LEAD ANTIKNOCK CONSUMPTION

Source	1955	1960	1965	1970	1975	1980	1985
Gasoline (10^9 gal/yr)	49.7	58.5	68.8	84.3	99.3	114.3	129.3
Lead Conc. (g Pb/gal)	2.25	1.95	2.27	2.50	--	--	--
Lead Usage (10^6 lb/yr)	261	251	344	464	--	--	--

Source: Ethyl Corporation, "Yearly Report of Gasoline Sales by States" (New York); "Lead Alkyls," *Chemical Economics Handbook*, Section 67, 15040A (Menlo Park, Calif., Stanford Research Institute).

2. Other Factors

The other areas of concern over the use of lead antiknocks involve the effects of lead on the combustion process and on engine and emissions control equipment deterioration.

It has been reported that the use of lead antiknocks produces an immediate rise in hydrocarbon emissions levels in a clean combustion chamber, which is further increased as deposits accumulate in the combustion chamber.[332] Lead is apparently without direct effect on carbon monoxide and nitrogen oxides emissions, but has been reported to reduce aldehyde emissions.[333] By far the most serious effect of lead is the increase in emissions due to deposit accumulation in combustion chambers and other critical engine parts. For example, the accumulation of lead deposits in certain types of exhaust recirculation systems has rendered some of these systems ineffective.[334]

Carburetor deposits, crankcase oil deterioration, bearing and exhaust system corrosion, etc., are problems which are made more serious through the use of leaded gasolines. In the past, practical solutions to these problems have been found and, on a value/benefit basis, the use of leaded gasolines was justified. As a result, cars designed to operate on leaded gasoline may suffer mechanical damage when operated on unleaded gasoline under high-speed conditions, resulting in an actual increase in pollution.

According to present technology, two general types of solutions exist for the elimination of nitrogen oxides, hydrocarbons and carbon monoxide from automobile exhaust. One system would be a dual-catalyst system, in which one catalyst reduces nitrogen oxides to nitrogen and by-products, and the other catalyst converts hydrocarbons and carbon monoxide to water and carbon dioxide. Both catalysts are deactivated by lead, and the nitrogen oxides catalyst is poisoned very rapidly. Leaded gasoline, therefore, would be unsuitable for use with such a system.

Given the high-compression ratio of many automobile engines today, only an unleaded fuel of high-octane rating could meet the requirements of a large segment of the car pollution if such a system were to be used. However, quantity production of such an untested fuel is feasible, given time.

Probably the quickest possibility for the elimination of lead from gasoline is to reduce the octane requirement of the fuel by reducing the compression ratio of automobile engines. Relatively low compression ratio engines, which might be equivalent to today's engines requiring regular grade gasoline, could then be used in conjunction with catalytic systems requiring lead-free gasoline. If these engines were to be developed and put on the market, cars requiring fuel quality equivalent to today's leaded premium would form a progressively smaller portion of the total car population. Unleaded or low-lead gasoline and catalytic mufflers, if developed for use, could be introduced in conjunction with the changed engines. However, lower compression ratio engines are less efficient. It should also be recognized that producing a given quantity of unleaded gasoline requires the use of more crude oil than the same quantity of leaded gasoline of the same octane rating.

Reference has been made to the fact that, with removal of lead, octane numbers will go down unless steps are taken to recover the lost octanes with additional refinery processing and that engine efficiency will be decreased as engines are redesigned to operate on lower octane fuels. Furthermore, the means available to increase the octane numbers of unleaded gasolines will generally result in higher aromatic concentrations.

The lower-efficiency engines required to operate on the unleaded gasolines will increase hydrocarbon emissions because of greater air and fuel consumption, but an offsetting increase is anticipated in the efficiency of the emissions control systems of these engines. Thus, the removal of lead must be viewed as a trade-off proposition in which certain gains are to be made but in which certain losses will also be incurred. It is the correct assessment of these gains and losses that, in the final analysis, will indicate whether lead removal is desirable.

The alternate system for elimination of nitrogen oxides, hydrocarbons and carbon monoxide from automobile exhaust involves engine modifications, including adjustments of spark advance and timing, in conjunction with exhaust-gas recirculation and after-burners. The fact that experimental vehicles have been developed which are capable of exhibiting very low emissions levels with leaded gasolines indicates that it is possible to solve the lead problem. These vehicles are reported to be at or near the 1976 standard emissions levels. Further work is required to determine whether these vehicles represent practical solutions to the emissions problem.

To date not all of the answers have been developed on the question of lead in gasoline, and additional work remains to be done. The resolution of the outstanding problems and the conversion to an unleaded economy, should this become necessary, requires a substantial measure of cooperation between the automotive and petroleum industries and the government. At present, the case for lead removal does not appear to have been established.

However, the industry recognizes that, while direct health effects of lead in gasoline do not appear to be a problem at present, the presence of lead in motor fuel does have broad and possibly serious implications in connection with efforts to reduce other pollutants in automobile exhaust emissions. If it is necessary to use catalytic devices to reach and maintain the 1975-1976 emissions standards, then it will probably be necessary to convert to an unleaded-gasoline economy. On the other hand, progress is being made in the development of control systems which will meet the 1975-1976 standards using leaded gasolines. In order to provide for the unleaded gasoline option, many oil companies have moved to market low-lead and unleaded gasolines, and by 1975 it is expected that one grade of an unleaded gasoline will be available nationwide. Until it is clear which of these gasoline/vehicle systems is clearly superior on a cost-effectiveness and customer-acceptance basis, the future use of lead antiknocks should not be ruled out.

D. Other Petroleum Motor Fuels

Although essentially all vehicles in the United States are designed for either gasoline or diesel fuel, some limited use has been made of other fuels in spark-ignition engines. The three fuels that have received most attention as alternates to gasoline are methane, propane and butane--the latter two, and mixtures thereof, are referred to as LPG. The physical properties of these light hydrocarbons are shown in Table 49.

All of these paraffinic light hydrocarbons are excellent fuels for the spark-ignition engine from the standpoint of combining high antiknock quality with

TABLE 49

PHYSICAL PROPERTIES OF LIGHT HYDROCARBONS

Fuel	Boiling Pt. °F	Liquid Sp. Gravity	Lower Heating Value, BTU/lb	Octane Ratings Research	(Clear) Motor
Methane	-259	0.300	21,297	120	120
Propane	- 44	0.500	19,768	112	97
Butane	31	0.579	19,494	94	90

Source: Edward F. Obert, *Internal Combustion Engines*, 3rd Edition.

clean-burning characteristics. Their chief disadvantages are their low boiling points, requiring pressurized fuel tankage on the vehicle--over 2,200 psi for CNG and over 200 psi for LPG--and their low volumetric heat of combustion.

In order to provide a standard article of commerce for vehicle design, LPG motor fuel has been defined in specifications by both the Natural Gas Processors Association (NGPA) and by the American Society for Testing and Materials (ASTM). NGPA Propane HD-5 is composed of a minimum of 90-percent propane, a maximum of 5-percent propylene and the remainder of ethane and butane. ASTM Special Duty Propane has a minimum of 95 Motor octane specification.[335] With either of these specifications, the consumer receives a fuel composed of 90 percent or more propane and with octane ratings higher than those of most premium gasolines.

Cycle performance calculations suggest that slightly better engine performance and fuel economy can be achieved on gasoline than on propane which, in turn, is better than that available from methane,[336] as follows:

Fuel	Relative Mean Effective Pressure	Relative Thermal Efficiency
Octane	100.0	100.0
Propane	90.7	92.8
Methane	81.0	92.1

However, when the normally gaseous fuels are utilized in urban vehicles with their many idle periods and stop-and-go operation, the fuel economy of either propane or methane may be as good as or slightly better than gasoline.[337] In this stop-and-go operation the gaseous fuels provide better distribution and lean operating mixtures--25-percent excess air in the case of methane. It is reported that the consensus of operational experience with natural gas has shown that 100 cubic feet (LHV = 100,000 BTU's) are equivalent in urban driving to one gallon of gasoline (LHV = 114,000 BTU's).[338]

Vehicle emissions with either LPG or CNG are significantly lower than with gasoline. First, of course, the pressurized fuel systems with the gaseous fuels preclude evaporative hydrocarbon losses. R. C. Lee and D. B. Wimmer compared the exhaust emissions of methane and propane to gasoline under optimum operating conditions for each fuel in a single-cylinder engine.[339] The percent of reduction in emissions compared with gasoline are--

	Reactive HC	CO	NO
Methane	99+	99+	59
Propane	87	99+	53

Either one of these gaseous fuels provides particulate-free exhaust.

Of the two light hydrocarbon fuels discussed above, LPG motor fuel is the only one that is widely distributed throughout the United States in a form ready for use by LPG-powered vehicles. Although natural gas is used widely in all large U.S. cities, facilities are not now installed to refuel vehicles requiring this gas at about 2,200 psi. In the isolated instances where methane is being used as a motor fuel, the vehicles are being refueled on a "time loading" basis.[340] In contrast, a network of LPG refueling stations already exists (many as part of existing gasoline stations) throughout the United States. Bulk plants provide a central distribution center for bottled and bulk propane, which is delivered to customers' storage by tank truck.

Section 3.
ENGINE TRENDS

A. Gasoline Engines

Technology for the control of gasoline engine emissions is now well advanced and will be applied during the survey period to production engines to reduce emissions. This is indicated by the emissions standards and factors shown in Tables 44 and 45 (pp. 308 and 309). Table 50 presents a listing of some of the means by which this control is to be achieved. Future work will be directed towards further development of these mechanical and gasoline systems and determining which of the several possibilities will prove to be the most effective, reliable, economical and acceptable to the consumer.

The ultimate levels to which it will be possible to reduce emissions with the various combinations of mechanical and gasoline systems shown in Table 50 are problems on which considerable effort will continue to be expended. Particularly important among these many problems is the question of the lower limit to which emissions control systems capable of operating on leaded gasoline can be developed. Catalytic devices using unleaded gasolines are capable of achieving very low emissions levels and will receive increasing attention during the forecast period. Emission reactivity is another aspect of control technology which may be applied in the future. High vapor pressure gasolines, LPG and LNG and vehicle systems designed to operate on such fuels will also continue to be developed and evaluated. By 1980 it is estimated that these efforts will have produced an essentially "non-polluting" automobile. Heavy-duty truck and bus engines operating in congested areas may require special fuels and control equipment in order to reduce emissions to the absolute minimum levels needed for this service.

B. Diesel Engines

The already low emissions from diesel engines will be further reduced by controlling overloading and improving fuel injection and combustion. Smoke emissions, which are controlled for the first time in the 1970 U.S. standards, will probably become subject to even greater control. Diesel engines operating in congested areas may employ special control equipment to remove the last traces of pollutants from the exhaust.

C. Gas Turbines

The emissions from aircraft and vehicle gas turbines will continue to be improved through improved injector and combustor design. Because of the very favorable emissions characteristics of gas turbines, it is possible that great-

TABLE 50

GASOLINE VEHICLE EMISSIONS CONTROL

Engine

Hydrocarbon and Carbon Monoxide	Nitrogen Oxides	Particulate
Lean mixture	Ultra-lean mixture	Exhaust oxidation
Exhaust oxidation	Controlled combustion	AIR-Sec burning
AIR-Sec burning	Exhaust recirculation	Catalytic oxidation*
Catalytic oxidation*	Catalytic reduction*	Filter-trap

Fuel System

Evap Control Devices	Closed Fuel System
Canister storage	Pressure tank
Crankcase storage	Fuel injection

Gasoline Modification

Unleaded gasoline*
Low C_4 & C_5 olefins
Low aromatic
Low volatility
High volatility
LPG, LNG & CNG

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* Catalytic devices require unleaded gasoline.

er use will be made of these engines in heavy-duty vehicles and off-highway equipment. Also, greater use of turbines for general aviation purposes is a good possibility.

D. Electric Engines

Gasoline-electric, battery-electric and other types of hybrid electric-engined vehicles exhibit very favorable emissions characteristics but suffer from range and acceleration performance limitations. These power plants will continue to be developed but, except for specialized uses, are not expected to be produced in significant quantities during the next few years.

E. Steam Engines

The development of a satisfactory steam engine vehicle presents many technical problems which are not subject to easy or early solution.

Chapter Ten

STATIONARY PLANTS—EMISSIONS AND TRENDS

Petroleum products are widely used in stationary plants for electric power generation, domestic and commercial heating, and manufacturing processes. When used as fuels they generate emissions as part of the combustion process. Evaporative emissions can also occur in commercial processes. The stationary-plant emissions that are receiving primary attention because of their impact on atmospheric quality are sulfur oxides, particulates, nitrogen oxides, carbon monoxide and unburned hydrocarbons.

The United States consumes more energy than any other single nation, and the trend is toward greatly increased consumption in the future.

Trends in electric generation indicate that coal is still the major fuel used and that its use for this purpose has continued to increase. However, future progress in nuclear plant development may slow the rate of growth of coal in the electric utility sector. This sector is currently the largest single source of sulfur dioxide and particulate air pollutants. Other air pollutants from this industry include nitrogen oxides, carbon monoxide and unburned hydrocarbons.

As for domestic and commercial heating, there are currently more than 30 million domestic and commercial space heating plants in the United States.[341] These plants burn coal, natural gas and petroleum fuel oil, and a few burn LPG. More than 2.5 million homes are heated with electricity. Commercial heating systems are commonly steam-type systems.

Emissions from domestic and commercial units are those commonly associated with fossil-fuel burning. Although the total quantities are less than from power generation, their effect on ground-level concentration in some cases can be greater, due to dispersed low-level emission sources.

Not all manufacturing processes have an important effect on the total emission of a particular pollutant and, generally speaking, the emissions related to use of petroleum are the result of its being used as a fuel. Emissions from uses of solvents are a notable exception.

Section 1.
SULFUR OXIDE EMISSIONS AND CONTROL TECHNIQUES

A. Emissions

"Sulfur enters the atmosphere as air pollutants in the form of SO_2, H_2S, H_2SO_4 and particulate sulfates; and as natural emanations in the form of H_2S and sulfates. On an annual basis, the tonnage of sulfur which is discharged into the atmosphere amounts to 220 x 10^6 tons. Of this sulfur, about one-third comes from air pollution sources, mostly in the form of SO_2, and the rest comes from natural processes. It is estimated that H_2S from natural processes accounts for almost one-half of the total sulfur released to the atmosphere, 100 x 10^6 out of the 220 x 10^6 tons.[342]

Sulfur dioxide has been a major pollutant ever since large quantities of soft coal were first burned and since the first smelting of copper sulfide ore.[343] Since the turn of the century, estimated sulfur dioxide from coal has increased 363 percent; from petroleum combustion, 864 percent; and from smelting, 707 percent. Coal, however, still accounts for 70 percent of the total worldwide sulfur dioxide emissions.

Between 1940 and 1965, sulfur dioxide emissions essentially doubled. Assuming no additional emissions controls, Table 51 shows the projected sulfur dioxide

TABLE 51

PROJECTED SO_2 EMISSIONS--1965-1990
BASED ON 1965 EMISSIONS FACTORS
(10^6 Tons per Year)

Source	1965	1970	1980	1990
Coal	102	103	105	107
Petroleum	29	38	62	100
Smelting Copper	13	16	23	33
Lead	1.5	2.0	3.3	5.4
Zinc	1.3	1.7	2.7	4.3
TOTAL SO_2 EMISSIONS (1965 control rate)	146.8	160.7	196.0	249.7
Percent Relative to 1965	100%	109%	134%	170%

Source: E. Robinson and R. C. Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants Supplement*, Prepared by the Stanford Research Institute for the American Petroleum Institute (Menlo Park, Calif., February 1968).

increases to 1980. Coal is expected to have the slowest growth rate, due to the probable increase of nuclear power and the substitution of liquid and gaseous fuels for power generation. However, refinement of flue-gas desulfurization processes could help increase coal's growth rate and, at the same time, reduce sulfur dioxide emissions from this source.

Of the estimated 1965 annual worldwide sulfur dioxide emissions rate of 146 x 10^6 tons, an estimated 70 percent resulted from coal combustion and 16 percent from the combustion of petroleum products, mainly residual fuel oil. Of the remainder, about 14 x 10^6 tons, or 10 percent, came from nonferrous smelting (copper, lead and zinc), and 6 x 10^6 tons, or 4 percent, from petroleum refining operations,[344] which is covered in an earlier section of this report. These estimates were obtained using emissions factors shown in Table 52. For coal, a factor of 3.3 tons of sulfur dioxide per 100 tons of coal produced was derived by Rohrman and Ludwig in 1965 based on 2 percent by weight sulfur in coal, with 10 percent of the sulfur remaining in the ash and assuming some shrinkage in transit from the mine to the user.

The following SRI breakdown of the sulfur dioxide emitted from petroleum product combustion shows minor contributions from gasoline, kerosine and distillate fuels. The emissions factors used to make these estimates are those also shown in Table 52.

Petroleum Source	Percentage of Total SO_2 Emitted from Petroleum Combustion
Gasoline	1
Kerosine	1
Distillate Fuel	9
Residual Fuel	89
	100

TABLE 52

SO_2 EMISSIONS FACTORS BASED ON PRODUCTION OR CONSUMPTION RATE

Combustion of:		Wt. % S*
Coal	3.3 T/100 T produced	2.0
Gasoline	1.8 lb/1,000 lb. consumed	0.09
Kerosine	4.8 lb/1,000 lb. consumed	0.24
Distillate	14.0 lb/1,000 lb. consumed	0.7
Residual	80.0 lb/1,000 lb. consumed	4.0

* Although the weight percent basis used to develop these factors is somewhat high, the factors are in general agreement with those shown on p. 21.

Source: Robinson and Robbins, *Sources, Abundance, and Fate of Gaseous Atmospheric Pollutants Supplement.*

National Air Pollution Control Administration (now the Air Programs office of EPA) studies of the sources of sulfur dioxide show that fossil fuels are responsible for 74 percent of the total (coal, 60 percent; oil, 14 percent), with 22 percent coming from other industrial processes and the remainder from miscellaneous sources such as transportation and solid-waste disposal.[345] A breakdown of these figures is shown in Table 53 for the years 1966, 1968 and 1970. Despite the small differences in emissions factors, these percentages agree fairly well with the SRI worldwide estimates already discussed.

Table 54 is a compilation by NAPCA of sulfur dioxide emissions factors.

TABLE 53

ESTIMATED NATIONWIDE SO_2 EMISSIONS (In Millions of Tons per Year)

Source	1966	1968	1970
Fossil Fuel Combustion in Stationary Sources	22.2	24.4	26.6
Ore Smelting	3.5	7.3	
Petroleum Refining	1.6		10.4
Miscellaneous	1.3	1.5	
TOTAL	28.6	33.2	37.0

TABLE 54

EMISSIONS FACTORS FOR SULFUR COMPOUNDS FROM FUEL COMBUSTION
(Pounds of SO_2)

Source	Emissions Factor	Assumptions
Coal	$\frac{38 \times S^*}{\text{Ton}}$	5% S in Ash
Natural Gas	$\frac{0.4}{10^6\ \text{CF}}$	$\frac{.14\ \text{Grain S}}{100\ \text{CF}}$
Process Gas	$\frac{2.86 \times C^\dagger}{10^6\ \text{CF}}$	
Fuel Oil	$\frac{158.8 \times S}{10^3\ \text{gal}}$	Includes SO_3 based on fuel density of 8.1 lb/gal.
Gasoline Powered Engine	$\frac{9}{10^3\ \text{gal}}$	.07% S
Diesel Powered Engine	$\frac{40}{10^3\ \text{gal}}$	.3% S
Wood	Negligible	
Aircraft	Negligible	

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* S=percent sulfur by weight.

† C=grains of sulfur/100 cubic feet of gas.

Source: HEW, *Control Techniques for Sulfur Oxide Air Pollutants*, NAPCA Publication No. AP-52 (HEW Public Health Service, Consumer Protection and Environmental Health Service, January 1969).

B. Control Techniques

A variety of approaches have been taken for controlling the emission of sulfur oxides from stationary sources. A natural and historical one is simply to attempt to substitute a different fuel. Fuel desulfurization methods have been in operation for a number of years. The present processing schemes used to produce low-sulfur fuel are designed to yield essentially a 1-percent-sulfur residual fuel. Reduction in the allowable level below 1 percent will further reduce the availability of the combined amounts of fuel with 1-percent and lower content. Flue-gas desulfurization has received widespread attention. Combustion modifications to increase the efficiency of the system are constantly under development.

1. Fuel Substitution

Fuel substitution is simply replacing high-sulfur fuels with low-sulfur fuels. This method would be the simplest one if availability and supply of low-sulfur-bearing fuels were no problem. Conversion to nuclear fuel or hydropower for electric power generation could also greatly reduce the emission of sulfur dioxide from power plants. An added benefit of fuel substitution is that particulate emissions may be reduced depending on the type of low-sulfur fuel used.

As mentioned above, the limited supplies of low-sulfur fuels and natural gas could not begin to fulfill the Nation's requirements for fossil fuels. Worldwide demand for low-sulfur fuels is also increasing, making it more difficult to obtain naturally occurring low-sulfur sources of fuel. Priorities have already been established for low-sulfur fuel usage in certain regions of the Nation. Local sulfur-in-fuel regulations, prompted by public concern, have been responsible for much of this fuel switching; for example, Philadelphia's Air Pollution Code, which virtually eliminates the use of coal after 1973, will require the public utilities to burn low-sulfur oil or gas.

Switching to electric heating could be considered a fuel substitute if it is produced from a non-combustion process; otherwise, the sulfur oxide emissions would just be relocated.

An earlier report by the National Petroleum Council detailed studies of the extent to which equipment had to be modified to burn various types of fuels in domestic, commercial and industrial heating equipment.[346] Results from that study are shown in Tables 55, 56 and 57.

TABLE 55

CONVERTIBILITY OF INDUSTRIAL HEATING EQUIPMENT

	Designed to Burn			Can Be Converted to Burn		
Type of Equipment	Coal	Oil	Gas	Coal	Oil	Gas
Incinerators		X*		No	NA†	Yes
			X	No	Yes	NA
Boilers	X	X		NA	NA	Yes
	X		X	NA	Yes	NA
		X	X	No	NA	NA
	X			NA	Yes	Yes
		X		Perhaps	NA	Yes
			X	Perhaps	Yes	NA
Process Heating	X	X		NA	NA	Yes
	X		X	NA	Yes	NA
		X	X	No	NA	NA
				NA	Yes	Yes
				Perhaps	NA	Yes
			X	Perhaps	Yes	NA
Heat Treating		X	X	No	NA	NA
		X		No	NA	Yes
			X	No	Yes	NA

---

* Designates the fuel that the equipment was designed to burn.

† Not applicable.

TABLE 56

CONVERTIBILITY OF COMMERCIAL HEATING EQUIPMENT

	Designed to Burn			Can Be Converted to Burn		
Type of Equipment	Coal	Oil	Gas	Coal	Oil	Gas
Unit Heaters		X*		No	NA†	Yes
			X	No	No	NA
Incinerators		X		No	NA	Yes
			X	No	Yes	NA
Portable Unvented Heaters (salamanders)	X			NA	No	No
		X		No	NA	No
			X	No	No	NA
Water Heaters	X			NA	Yes	Yes
		X		No	NA	Yes
			X	No	Perhaps	NA
Warm-air Furnaces	X			NA	Yes	Yes
		X		No	NA	Yes
			X	No	Perhaps	NA
Boilers--Steam or Hot Water	X			NA	Yes	Yes
		X		No	NA	Yes
			X	No	Perhaps	NA
		X	X	No	NA	NA

---

* Designates the fuel that the equipment was designed to burn.

† Not applicable.

TABLE 57

CONVERTIBILITY OF DOMESTIC HEATING EQUIPMENT

	Designed to Burn			Can Be Converted to Burn		
Type of Equipment	Coal	Oil	Gas	Coal	Oil	Gas
Incinerators		X*		No	NA†	Yes
			X	No	Perhaps	NA
Unvented Space Heaters		X		No	NA	No
			X	No	No	NA
Vented Space Heaters	X			NA	Difficult	Difficult
		X		No	NA	No
			X	No	No	NA
Recessed Wall Heaters		X		No	NA	Perhaps
			X	No	No	NA
Water Heaters	X			NA	Probably	Probably
		X		No	NA	Perhaps
			X	No	No	NA
Warm-air Furnaces	X			NA	Yes	Yes
		X		No	NA	Yes
			X	No	No	NA
Boilers--Steam or Hot Water	X			NA	Yes	Yes
		X		No	NA	Yes
			X	No	Perhaps	NA

---

* Designates the fuel that the equipment was designed to burn.

† Not applicable.

The switch of industries and power plants to natural gas has overtaxed the already tight supply used for home heating, cooking and air-conditioning. From the point of view of atmospheric quality, the greatest gain is to have small users burn the lowest sulfur fuel available, since they emit pollutants at low altitudes where the emissions have a greater effect on ground-level concentrations. Larger sources are better equipped to handle higher sulfur fuels and, in the future, will either be equipped with flue-gas desulfurization processes or supplied with low-sulfur fuel, or both.

2. Fuel Desulfurization

The methods of fuel desulfurization in operation over the past years have previously been aimed at improving the overall profitability of the plant or operation. For example, normal coal preparation which removes clay, shale and rocks also happens to remove some pyrite sulfur (FeS_2). Liquefaction of coal involves sulfur removal; however, this research is primarily aimed at upgrading coal to more valuable products. Desulfurization of distillate fuels and natural gas, however, is done primarily to meet sulfur specifications. Impending and current air pollution regulations setting stringent sulfur specifications on fuels has hastened the development of desulfurization processes.

The largest single sulfur dioxide source, coal, is the most difficult to desulfurize. Coal preparation techniques are used with varying results, depending on the specific type of coals used. However, few coals are cleaned extensively. Large, commercially operating coal liquefaction and gasification processes probably will not have any significant impact on the low-sulfur fuel situation during the 1970's.

Stationary sources burning petroleum fuels contribute roughly 16 percent of the total sulfur dioxide emitted to the atmosphere. Since nearly 90 percent of the sulfur oxides produced by these petroleum fuels comes from burning the heavier residual fraction, it would seem logical to concentrate efforts on residual fuel desulfurization. Direct desulfurization of high-sulfur residuals can presently be accomplished only on certain low-metal-content residuals, consequently limiting the volume of low-sulfur material obtained from this process. Low-sulfur residual is also obtained by topping naturally occurring low-sulfur crudes. Residual fuels produced from this type of operation range in the 0.5-percent sulfur level, or lower, depending on crude source. The volume of material available from these low-sulfur crudes is limited due to their location, principally North and West Africa, and the ever-increasing worldwide competition for these low-sulfur crudes.

The most common method of obtaining 1-percent-sulfur fuels is by blending high-sulfur resid with desulfurized low-sulfur vacuum distillates. This technique is being used to supply most of the residual fuel to the East Coast markets. Desulfurization of the overhead from vacuum distillation of reduced crude can produce fuel having a sulfur content as low as 0.3 percent; however, the use of only this portion, with no back blending of residual, would greatly reduce the volume of 1-percent-sulfur fuel, which is currently in critically short supply.

The Caribbean refineries are the major source of low-sulfur fuel for the East Coast market, and in recent years have invested heavily in desulfurization processes. Table 58, from the *Oil & Gas Journal*, shows the worldwide activity in these processing schemes.

When the sulfur content of a residual fuel from a typical Venezuelan crude is reduced to 1 percent, the viscosity is simultaneously reduced to the minimum ASTM specifications for No. 6 fuel oil (45 SSF at 122 degrees Fahrenheit). When the sulfur content is reduced to 0.5 percent, the viscosity reaches the minimum allowed by import regulations (145 SSU at 100 degrees Fahrenheit). These fuels may be produced by direct residual desulfurization or by delayed coking and solvent deasphalting followed by blending with a vacuum gas oil. Due to the high metals content of Caribbean crudes, current desulfurization processes are less reliable and more costly for desulfurizing to about 1 percent.

TABLE 58

TYPICAL RECENT PETROLEUM DESULFURIZATION ACTIVITY

Company	Location	Process	Feed
Cities Service	Lake Charles, La.	H-Oil	Residual Oil*
Idemitsu Kosan	Chiba, Japan	Isomax	Residual Oil*
Shell	Curacao, N. Ant.†	Shell HDS	Vacuum Gas Oil*
Humble	Bayonne, N. J.	Blending*	--
Humble	Linden, N. J.	H-Oil	Residual Oil
Creole	Amuay, Venezuela	Esso HDS	Vacuum Gas Oil
Lago	Aruba, N. Ant.†	Esso HDS	Vacuum Gas Oil
Shell	Cardon, Venezuela	Shell HDS	Vacuum Gas Oil
Aminoil	Kuwait	Isomax	Atmos. Residuum
Kuwait National Petroleum	Kuwait	H-Oil	Residuum
Idemitsu Kosan	Japan	Isomax	Residuum
Dikyo Oil	Japan	Gulfining	Vacuum Gas Oil
Nippon Petroleum	Japan	Isomax	Vacuum Gas Oil
Toa Nenryo	Japan	Esso Hydrofining‡	Vacuum Gas Oil
	Japan	Isomax	Vacuum Gas Oil
Atlantic Richfield	Wilmington, Calif.	Coker Expansion	--
Phillips Petroleum	Woods Cross, Utah	De-asphalting	Asphalt
Standard of California	El Segundo, Calif.	Coker	--
Texaco	Wilmington, Calif.	Coker§	--

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* Plants in operation; others are under construction or planned.

† Netherlands Antilles.

‡ Two units.

§ Texaco is also using their partial oxidation synthesis process to make hydrogen, using residual oil as feed.

Source: E. W. Sledjeski and R. E. Maples, "How Residual Sulfur Limits Affect Refining," *Oil & Gas Journal*, Vol. LXVI, No. 18 (April 29,1968), pp. 55-63.

Descriptions of commercially operating desulfurization processes have been adequately presented in the literature.

A recent catalyst development claims direct hydrodesulfurization of residual fuels to the 1-percent-sulfur level.[347] Although still under development, the new catalyst permits lower operating pressures and temperatures, thereby cutting costs and boosting liquid yields.

Gas desulfurization is usually necessary to remove sulfur compounds for reasons other than air pollution considerations. Elemental sulfur causes plugging of equipment; hydrogen sulfide is highly toxic and causes rapid corrosion in steel when moisture is present or at elevated temperatures, and is very reactive with copper or copper-bearing alloys. Mercaptans, disulfides, carbonyl sulfide and thiophenes are malodorous and corrosive. Natural gas specifications usually call for very low amounts of hydrogen sulfide (below 1/4 grain/100 SCF) and total sulfur (below 10 grains/100 SCF). With such low sulfur specifications, burning of this fuel contributes very little to the overall sulfur dioxide problem.

3. Flue-Gas Desulfurization

This area has received widespread attention, but full-scale, commercial flue-gas desulfurization processes for large installations are still not fully operable.

Progress in developing flue-gas desulfurization processes has been slow due to the magnitude and complexity of the problem. Although impressive advances in research are being made, stack-gas removal techniques are not likely to be in wide use in time to meet existing and proposed legislative targets. When, however, these processes become practical, power plants can utilize high-sulfur fuels more extensively, thus freeing low-sulfur fuels for space heating requirements.

Over the last several years there have been a number of processes applied to the control of sulfur oxides from large stationary sources. *Results from all these prototype units confirm that there is still no one process that can adequately control sulfur oxide pollution from large sources, such as electric power plants.* A 1970 report, *Abatement of Sulfur Oxide Emissions from Stationary Combustion Sources* by the National Academy of Engineering and the National Research Council, concluded that commercially proved technology for control of sulfur oxides from combustion processes used for generating electricity does not yet exist.

This view is still held by most people in the field. The only potential use of flue-gas desulfurization techniques will be on *large new* sources; however, their use will be very limited over the next 5 years. Beyond this time the application of flue-gas desulfurization will depend almost entirely on the performance of the current generation of prototype units. Much work still remains to be done if these processes are to meet the challenges posed by air pollution regulations.

There are a number of flue-gas desulfurization systems which have been adequately described in the literature. They are listed below with a few comments as to their performance up to this time.

- *Combustion Engineering's* limestone wet scrubbing system uses pulverized limestone rock fed to the burners with the coal. Partial reaction with sulfur compounds takes place in the furnace with completion of the reactions occurring in packed marble-bed scrubbers located before the stack. Although described as one of the more advanced processes, the two prototype units have been continually plagued with problems since start-up in 1968. Extensive modifications have improved the operations but only enough to give a 60-percent and 80-percent sulfur dioxide-removal efficiency, far short of what is required for proper control of sulfur dioxide. A third modified system will go onstream later this year, and United Engineers is considering this process for possible use in a new full-scale power station installation in Pennsylvania. The Pennsylvania Electric Association is less enthusiastic about a full-scale unit, stating that any flue-gas desulfurization technology being evaluated was not sufficiently reliable for full-scale installation.

- *Monsanto's Cat-OX* system uses a high-temperature electrostatic precipitator for particulate removal and a proprietary catalyst for oxidation of sulfur dioxide to sulfur trioxide. The sulfur trioxide is then condensed as sulfuric acid in a packed bed absorber. Based on prototype operation, the process is probably limited to new plants, but to date Monsanto does not have any full-scale orders. This, too, is one of the processes considered as a possibility by United Engineers for a new site in Pennsylvania.

- *Wellman-Lord's* process utilizes a potassium sulfite liquid to chemically absorb the sulfur dioxide, then regenerates it as dry sulfur dioxide, which is then liquefied or converted to free sulfur. The two prototype units have not performed satisfactorily and there are no plans for a full-scale installation.

- *Chemico-Basic's* process employs a high-velocity venturi wet scrubbing system with either a limestone slurry or a magnesium oxide slurry depending on whether it is a "throwaway" or "recovery" operation. This process has two prototypes, one in service and one in the planning stages.

- *Babcox and Wilcox/ESSO Research* and 16 utility companies are developing a system using a hot side electrostatic precipitator followed by a fixed bed sorbent reactor to remove sulfur dioxide. This system is still undergoing testing.

- *UOP's* wet scrubber system accomplishes particulate removal, then an alkaline (sodium carbonate) slurry removes the sulfur compounds from the flue gas. A prototype is planned for later this year. UOP also licenses Shell's dry process which utilizes a copper on alumina catalyst. Shell's process has been tested on a heavy fuel oil-fired plant in Europe and removed 90 percent of the sulfur dioxide. The process utilizes parallel passage reactors with beds of cupric oxide/alumina catalyst. The sulfur dioxide deposits as $CuSO_4$. Through a regeneration process, the catalyst is recycled and elemental sulfur recovered by conventional techniques. UOP estimates it will be 1975 or 1976 before significant use will be made of stack-gas scrubbing. The Committee judges even this date to be too optimistic.

- *Stone & Webster--Ionics, Inc.'s* process is a patented electrolytic membrane diaphragm cell that regenerates caustic soda used for washing the flue gas in a wet scrubber. Dry sulfur dioxide is recovered. The company still has not run a prototype unit.

- *Atomics International*, a division of American Rockwell, has developed a molten carbonate process which, after electrostatic precipitation, contacts the flue gas with a molten mixture of lithium, sodium and potassium carbonate. The carbonates are partially converted to sulfites and sulfates. The sulfides react with carbon dioxide and water to form hydrogen sulfide which can then produce sulfuric acid or sulfur. This process is just in the pilot plant stage.

- *Menardi Bag Filter.* A bag filter with a limestone injection system has been in operation at the Alamitas Station of Southern California Edison Co. since 1965. The initial objective was to control visible emissions when firing residual oil. This objective was accomplished, although they encountered excessive bag replacements. There is little information available on the sulfur dioxide-recovery aspects of this system.

- *Consolidated Coal Co.'s* potassium formate process seems valid but still needs pilot plant testing.

- *Research-Cottrell* presumably will use their patented Flooded Disc wet scrubbers with an alkaline slurry system to remove sulfur dioxide.

- *Granular bed devices* are also being considered to simultaneously remove particulates and sulfur dioxide; however, they are far from any commercial application.

- The *Grillo-Werke AG-AGS* process uses a magnesium oxide and magnesium dioxide solution. The magnesium oxide functions as an absorbing agent, and the magnesium dioxide as an oxygen donor. Reaction with sulfur dioxide yields sulfates, sulfites and bisulfites. Regeneration then gives off sulfur dioxide for recovery. Successfully tested on a commercial scale by Grillo-Werke AG, at this stage it offers little more than the U.S. processes.

- The *Sulfacid* process and the *Bergbau-Forschung G.m.b.H.* process absorbs sulfur dioxide on activated coke at 100 degrees centigrade. The water and oxygen also absorbed convert the sulfur dioxide to sulfuric acid within the coke capillaries. Regeneration of the coke is by water or heat treatment.

- The *Bischoff* process utilizes pulverized lime hydrate, calcium oxide and fine white lime in a slurry to scrub out sulfur dioxide. Tests on a power plant in 1968 indicate a promising 80- to 90-percent sulfur dioxide removal, but larger scale tests are needed to determine the process's feasibility.

- The *Reinluft* activated-char process has given good results in Europe but still requires important plant-design changes and trial testing before full-scale operation is possible.

TABLE 59

SULFUR RECOVERY FROM STACK GASES

Process	Status	Comments
(a) Monsanto Cat-OX	Piloted on 15-MW plant; possible commercial demo by 1973.	Requires boiler modification.
(b) Wellman-Lord	Piloted in 1969.	Commercial unit being installed on sulfuric acid plant.
(c) Esso-B & W	Bench-scale unit in operation; 25-MW pilot being planned.	Requires boiler modification; commercial process by 1973 is objective.
(d) Magnesium Oxide Scrubbing	Pilot studies being conducted.	
(e) Formate Scrubbing	Bench-scale studies conducted.	
(f) Ammonia Scrubbing	Bench-scale studies conducted years ago.	
(g) Westvaco Char	Pilot studies being conducted.	
(h) Molten Carbonate	Bench-scale studies conducted.	Mainly new plants with modified boilers.
(i) Sodium Bicarbonate Adsorption	Pilot studies conducted.	
(j) Modified Claus	Bench-scale studies conducted.	Requires hydrogen for sulfur removal process.
(k) Catalytic Chamber	Bench-scale studies conducted.	
(l) Ionics, S & W	Pilot-level studies conducted.	
(m) Alkalized Alumina	Engineering and cost analysis.	Further work unjustified.
Limestone Processes		
(a) Wet Scrubbing (Combustion Engineering)	Units on 2 existing plants (125 MW); third unit planned for 430-MW plant.	Problems in scrubber optimization and waste removal.
(b) Dry Removal	One unit being installed on 175-MW plant.	Possible worsening of fly ash problem.
Combustion Processes		
(a) Fluidized Bed	Piloted in U.S.; English studies indicate 20- to 30-MW pilot can be completed by 1972.	Applicable only to new plants.
(b) B, S and B Process	Feasibility studies being conducted; pilot plant design begun.	New concept in boiler design.

The 16 processes described herein bear out the earlier conclusion that there does not exist a satisfactory commercial flue-gas desulfurization process. There is also the problem of continuity of operation, which is necessary 99.9 percent of the time with power plants. Taking the optimistic view that one of these processes will become commercially available in the next 2 years, then it would be another 4 years before the process could be applied to a new power plant, thus putting it in the late 1970's. The Committee does not foresee the widespread use of flue-gas desulfurization on new power stations until the late 1970's or even 1980. The Council on Environmental Quality thinks stack-gas scrubbing will be commercially available by 1975. Retrofitting existing plants that have not left sufficient space for these processes may never come about. Sulfur oxide control from these plants would more likely come about through fuel switching to lower-sulfur fuels.

Table 60 shows the extent of research into the field of dry additives, employed in both the fuel and the flue gas. The results reported in Table 60, with the possible exception of the material nahcolite, show removal efficiencies which are too low to allow the use of 3-percent sulfur coals (common in the Midwest in cities requiring the use of 1.5-percent-sulfur fuels, or its equivalent).

4. Increased Process Efficiency

Process improvements to increase the efficiency of the systems so that they use less fuel will, in turn, reduce sulfur dioxide emissions. Large modern steam electric power plants use roughly 8,500 BTU's per KWH of electricity compared to 10,000 BTU's per KWH for older, smaller plants.

Fuel usage may be reduced by these relatively simple operational actions:

- Washing turbine blades
- Adjusting turbine control valves to ensure proper lift
- Adjusting for maximum turbine throttle pressure
- Adjusting preheater seals and feedwater heaters
- Periodically cleaning condensers
- Periodically cleaning secondary and reheat superheaters.

Efficient boiler operation requires that the optimum air-to-fuel ratio be maintained. The low-excess air-fired method gives 1- to 2-percent improvement in boiler efficiency and is one of the most effective improvements that can be made in existing plants. Control of fuel and air is automatic on all large modern boilers.

Plant efficiency also improves with increasing unit size, as shown in Figure 84.

Diesel and gas turbine generators are being installed at many generating stations to meet peak demands. These units, available in many sizes up to about 25 megawatts each, can reach full load very rapidly from a cold start. Because such units burn light fuel oils or natural gas, they do not emit large quantities of sulfur dioxide.

Another means of attaining system flexibility is the pumped-storage technique. During periods of low power demand, excess generating capacity is used to pump water to an elevated reservoir. Then, during peak demand periods, the potential energy of the water can be converted to electricity by a conventional hydroelectric plant. In order to provide an overall sulfur dioxide reduction, the electricity used to pump water to the elevated reservoir must be provided by a nuclear plant, or a thermal plant burning a low-sulfur fuel.

Extra-high-voltage transmission networks also provide system flexibility by allowing utilities in one area to provide power to cities hundreds of miles away.

TABLE 60

RESULTS OF SOME TRIALS OF DRY ADDITIVES FOR SULFUR-DIOXIDE REMOVAL

Test Identification	Special Notes	Material	Application: Method	Application: Maximum Temp., °F	Application: Rate lb/Ton	Stoichiometric	% Removal of SO_2
Chicago series	Underfeed stoker	3/16-in. dolomite	With fuel		300	70.4	25.7
Chicago series	Underfeed stoker	Pulv. dolomite	With fuel		344	101.2	26.3
Chicago series	Underfeed stoker	Pulv. dolomite	Over fuel	2,300	225	65.2	19.4
Chicago series	Underfeed stoker	Red mud	With fuel		100	---	16.8
Chicago series	Underfeed stoker	Red mud	Top of furnace	1,000	187	---	22.2
Chicago series	Underfeed stoker	Red mud	Top of furnace	1,000	291	---	39.3
Chemcoke* series	Chain-grate stoker	Red mud	Above fuel bed	1,280	151	---	20.0
Chemcoke* series	Chain-grate stoker	Red mud	Above fuel bed	1,280	227	---	25.0
General Motors series	Pulverized coal unit	Pulv. dolomite	With fuel	2,800	450	197.0	33.0
General Motors series	Pulverized coal unit	Pulv. limestone	With fuel	2,800	450	189.0	21.0
General Motors series	Pulverized coal unit	Pulv. dolomite	In furnace	1,900	500	209.0	37.0
General Motors series	Pulverized coal unit	Pulv. limestone	In furnace	1,900	486	220.0	33.5
General Motors series	Spreader stoker	Pulv. limestone	Through over-fire jets	2,300	220	110.0	23.0
Precipitair series	Oil-fired unit	Nahcolite	Into flue gas ahead of baghouse	240	---	100.0	72.9
Precipitair series	Spreader stoker	Nahcolite	Into flue gas ahead of electrostatic precipitator	310	---	100.0	64.0

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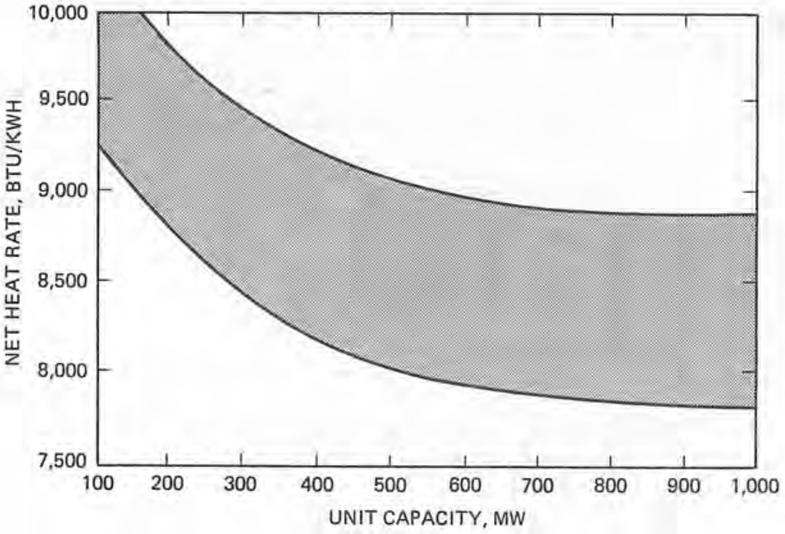
* Tests made at Chemcoke Research Facility of Peabody Coal Company as part of NAPCA Contract No. PH-22-68-68.



Source: R. K. Evans, "The Spectacular Story of Size," *Power,* Vol. CX, No. 12 (December 1966), pp. S2 - S5.

Figure 84. Comparison of Plant Size and Heat Rate.

Greater process efficiency also can be achieved by changes in the basic techniques used to generate electricity. The following methods of power generation represent techniques that are still in the early stages of development but offer considerable potential advantages over present methods in that they use less fuel for a given electrical output and thus emit less sulfur dioxide.

a) High-Pressure Combustion

The design of a pressurized coal-fired furnace requires a new method of fuel burning, such as a fluidized-bed technique.[348]

b) Two-Step Combustion

This approach uses a two-stage process in which a first gasification stage yields concentrated fuel gas containing hydrogen sulfide. The hydrogen sulfide can be easily removed and converted into elemental sulfur, and the resulting sulfur-free fuel gas burned in a second combustion step. However, this method has a practical problem in that the gas must be cooled for scrubbing.

c) Magnetohydrodynamics

Another new concept involves the use of an MHD generator as the first step in power generation, or an MHD "topping plant" combined with a conventional steam "bottoming plant." Basically, MHD is a technique in which the thermal energy of a hot gas (supplied by any type of fuel) is converted first to kinetic energy and then directly to electricity by the mass interaction of an electromagnetic field with the hot, rapidly moving, electrically conductive gas.[349]

d) Electrogasdynamics

EGD, like MHD, is a direct energy conversion technique in which the kinetic energy of a flowing gas is directly converted into low-amperage, high-voltage electricity.[350]

5. Dispersion from Stacks

Tall stacks do not reduce the quantity of sulfur dioxide emitted to the atmosphere, but do provide a means of allowing the natural atmospheric turbulence to dilute the pollutants before reaching ground level. Natural atmospheric removal processes would be the only method of sulfur dioxide removal if tall stacks were used everywhere. The effectiveness of even lowering ground-level pollutant concentrations, by the use of tall stacks, is severely curtailed by unfavorable terrain and/or meteorological conditions. There are, however, certain locations where their use is beneficial.

Section 2.
PARTICULATES EMISSIONS AND CONTROL TECHNIQUES

A. Emissions

The solid particulate matter emitted to our atmosphere includes both organics and inorganics from fuel combustion, charred cellulose and ash from incineration, oxidized gasoline additives (mainly lead compounds), mineral dust from rock crushing and from asphaltic and Portland cement batching plants, metallurgical fume, catalyst fines and other miscellaneous dusts from industrial processes. Some finely divided liquid aerosols from fuel combustion, asphalt blowing and sulfuric and phosphoric acid manufacture also make up part of the total particulate picture.

Of the 11.5 million tons of particulates produced in the United States during 1966,* 6 million tons (52 percent) were emitted from industrial sources, including industrial fuel burning; 3 million tons (26 percent) from power generation; 1 million tons (9 percent) from incineration; 1 million tons (9 percent) from space heating; and 0.5 million tons (4 percent) from mobile sources.[351]

Combustion of fuels from stationary sources, both industrial and power plants, is the largest particulate source category. The percentage of heat supplied by each fuel is by no means proportional to its particulate emissions. For example, in the New York metropolitan area, burning of anthracite and bituminous coals provides only 15 percent of the area's heat requirements, yet it contributes 60 percent of the combustion fuel particulate total. Residual and distillate fuels produce 63 percent of the heat, but only 37 percent of the fuel particulate, while natural gas provides 22 percent of the heat but only 3 percent of the fuel particulate total.[352]

When hydrocarbon fuels are burned in a deficiency of oxygen, carbon particles will be emitted. These particles will increase with poor fuel atomization and inadequate mixing, producing a visible blackness to the plume.

Table 61 summarizes the U.S. estimated average particulate emissions from stationary combustion sources.

Table 62 supports the fact that the quantity of inorganic solid particulates from combustion sources is entirely dependent upon the characteristics of the fuel. There is no measurable inorganic ash in exhaust gases from the combustion of natural gas or other clean gaseous hydrocarbon, except for that small quantity attributable to the dust usually present to some degree in all air used for combustion. Distillate fuels do not contain appreciable amounts of ash. Residual oils, however, contain inorganic ash-forming materials in quantities up to 0.1 percent by weight. The ash compounds show up as finely divided particulates in exhaust gases. Residual fuels contain a higher percentage of ash than distillates.

In general, however, the emissions factors for particulate air pollutants are not precise indicators of what particulate emissions might be from any individual process.

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*A more recent estimate reports nationwide emissions of particulates to have been 28.6 million tons in 1968 (HEW, *Nationwide Inventory of Air Pollutant Emissions 1968)*. However, this estimate includes apparent (as opposed to actual) changes due to changes in emissions factors and the inclusion of new sources such as forest fires (6.7 million tons per year). The net change in emissions from fuel combustion was reported to be down 0.3 million tons from 1966.

B. Control Techniques

The general methods of controlling particulate emissions include gas cleaning and collection, fuel substitution, fuel modification, more efficient fuel utilization, relocation of the emission source and stack dispersion. The first four methods reduce the quantity emitted at the source. The last two take greater advantage of natural reduction of concentrations by atmospheric forces.

1. Gas Cleaning and Collection

This method is by far the most widely used and accepted method of controlling particulates from stationary sources. Table 63 (p. 342) lists five commercially operating systems and two under development that are used to control various process emissions. A brief description of each system shown in Table 63 is given below. For a more detailed description, reference is made to HEW's *Control Techniques for Particulate Air Pollutants.*[353]

A *settling chamber* is a low efficiency, low cost, low pressure drop gas cleaning device but is used on very few gas-, oil- or coal-fired combustion sources.

TABLE 61

ESTIMATED AMOUNT AND CONTROL STATUS FOR PARTICULATE EMISSIONS FROM STATIONARY COMBUSTION SOURCES IN 1966

Fuel and Source	Uncontrolled Emissions* (10^6 Tons)	Estimated Control Status in 1966† (Percent)	Estimated Emissions in 1966 10^6 Tons	% of Total
Anthracite Coal				
Household & Commercial	0.05	Negligible	0.05	1.1
Industrial	0.04	62.0	0.02	0.4
Power	0.17	86.5	0.02	0.4
Subtotal	0.26	--	0.09	1.9
Bituminous and Lignite Coal				
Household & Commercial	0.24	Negligible	0.24	5.4
Industrial	2.29	62.0	0.87	19.5
Power	21.14	86.5	2.85	64.1
Subtotal	23.67	--	3.96	89.0
Petroleum‡				
Household & Commercial	0.08	Negligible	0.08	1.8
Industrial	0.17	Negligible	0.17	3.8
Power	0.03	Negligible	0.03	0.7
Subtotal	0.28	--	0.28	6.3
Natural Gas				
Household & Commercial	0.06	Negligible	0.06	1.3
Industrial	0.05	Negligible	0.05	1.1
Power	0.02	Negligible	0.02	0.4
Subtotal	0.13	--	0.13	2.8
TOTAL	24.34	--	4.46	100.0

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* Basis for estimates:

a) Emissions factors--Table 62, p. 341.
b) Energy consumption--source material, Table 3-2, p. 7.
c) Fuel properties--
    Anthracite coal--13,000 BTU/lb., 10-percent ash
    Bituminous coal--12,000 BTU/lb., 10-percent ash
    Distillate oil--140,000 BTU/gal.
    Residual oil--150,000 BTU/gal.
    Natural gas--1,000 BTU/cu. ft.

† W. W. Moore, *Reduction in Ambient Air Concentration of Fly Ash--Present and Future,* Publication No. 1649 (Washington, D.C., HEW Public Health Service, 1967), pp. 170-178.

‡ Excludes naphtha, kerosine, range oil and LPG.

Source: HEW, *Control Techniques for Particulate Air Pollutants,* NAPCA Publication No. AP-51 (HEW Public Health Service, Consumer Protection and Environmental Health Service, January 1969).

TABLE 62

PARTICULATE EMISSIONS FACTORS

Fuel Combustion--Stationary Sources	Particulate Emission Rate*
Coal	
Pulverized:	
General (anthracite and bituminous)	16A† lb/ton of coal burned
Dry Bottom (anthracite and bituminous)	17A lb/ton of coal burned
Wet Bottom (anthracite and bituminous)	
Without fly ash reinjection	13A lb/ton of coal burned
With fly ash reinjection	24A‡ lb/ton of coal burned
Cyclone (anthracite and bituminous)	2A§ lb/ton of coal burned
Spreader Stoker (anthracite and bituminous)	
Without fly ash reinjection	13A lb/ton of coal burned
With fly ash reinjection	20A‡ lb/ton of coal burned
All Other Stokers (anthracite and bituminous)	
Greater than 10 x 10^6 BTU/hr	5A lb/ton of coal burned
Less than 10 x 10^6 BTU/hr	2A§ lb/ton of coal burned
Hand-fired equipment (bituminous coal only)	20 lb/ton of coal burned
Residual Oil	
Greater than 100 x 10^6 BTU/hr	10 lb/1,000 gallons of oil burned
Less than 100 x 10^6 BTU/hr	23 lb/1,000 gallons of oil burned
Distillate Oil	
10 to 100 x 10^6 BTU/hr	15 lb/1,000 gallons of oil burned
Less than 10 x 10^6 BTU/hr	8 lb/1,000 gallons of oil burned
Natural Gas	
Greater than 100 x 10^6 BTU/hr	15 lb/million ft^3 of gas burned
10 to 100 x 10^6 BTU/hr	18 lb/million ft^3 of gas burned
Less than 10 x 10^6 BTU/hr	19 lb/million ft^3 of gas burned
Wood‖	10 lb/ton of wood burned

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* Emissions rates are those from uncontrolled sources, unless otherwise noted.

† Where letter "A" is shown, multiply number given by the percent ash in the coal.

‡ Value should not be used as emissions factor. Values represent the loading reaching the control equipment always used on this type of furnace.

§ Revised from 5A.

‖ New York State Department of Health, Bureau of Air Pollution Control Services, "Procedure for Conducting Comprehensive Air Pollution Surveys" (Albany, New York, August 18, 1965).

Source: HEW, *Control Techniques for Particulate Air Pollutants.*

TABLE 63

OPTIMUM EXPECTED PERFORMANCE OF VARIOUS TYPES OF GAS CLEANING SYSTEMS FOR STATIONARY COMBUSTION SOURCES

	Removal of Uncontrolled Particulate Emissions, Percent						
	Systems in Operation					Systems Under Development	
Sources	Settling Chambers	Large Diameter Cyclones	Small Diameter Cyclones	Electrostatic Precipitators	Stack Sprays	8-inch Pressure Drop Scrubbers	Fabric Filters
Coal-fired							
Spreader, chain grate & vibrating stokers	50*	60*	85*	99.5†	60‡	99+§	99.5‖
Other stokers	60*	65*	90*	99.5†	80‡	99+§	99.5‖
Cyclone furnaces	10*	15*	70*	99.5†	#	#	#
Other pulverized coal units	20*	30*	80*	99.5†	#	99+§	99.5‖
Oil-fired	5**	10**	30**	75.0††	#	#	#

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* Sources: "Criteria for the Application of Dust Collectors to Coal-Fired Boilers," Results of an IGCI/ABMA Joint Technical Committee Survey; "Modern Dust Collection for Coal-Fired Industrial Heating and Power Plants," *Fuel Engineering Handbook*, Section F-2 (Washington, D.C., National Coal Association, September 1961).

† Source: W. W. Moore, *Reduction in Ambient Air Concentration of Fly Ash--Present and Future*, Publication No. 1649 (Washington, D.C., HEW Public Health Service, 1967), pp. 170-178.

‡ "Stack Sprays to Reduce Dust Emissions During Soot Blowing," BCR Aid to Industry, 500-330 (Pittsburgh, Pa., Bituminous Coal Research Inc., 1965).

§ W. A. Pollock, J. P. Tomany and G. Frieling, "Removal of Sulfur Dioxide and Fly Ash from Coal Burning Power Plant Flue Gases," Pub. 66-WA/CD-4 (New York, American Society of Mechanical Engineers, 1966), p. 8.

‖ R. E. Sommerlad, "Fabric Filtration--'State of the Art'" (Livingston, N.J., Foster Wheeler Corp., March 1967).

Insufficient data for estimate.

** Efficiency estimated--not commonly used.

†† Estimate based on private reports of field experience.

Source: HEW, *Control Techniques for Particulate Air Pollutants*.

TABLE 64

ADVANTAGES AND DISADVANTAGES OF COLLECTION DEVICES

Collector	Advantages	Disadvantages
Gravitational	Low-pressure loss, simplicity of design and maintenance.	Much space required. Low collection efficiency.
Cyclone	Simplicity of design and maintenance. Little floor space required. Dry continuous disposal of collected dusts. Low to moderate pressure loss. Handles large particles. Handles high dust loadings. Temperature independent.	Much head room required. Low collection efficiency of small particles. Sensitive to variable dust loadings and flow rates.
Wet Collectors	Simultaneous gas absorption and particle removal. Ability to cool and clean high-temperature, moisture-laden gases. Corrosive gases and mists can be recovered and neutralized. Reduced dust explosion risk. Efficiency can be varied.	Corrosion, erosion problems. Added cost of waste-water treatment and reclamation. Low efficiency on submicron particles. Contamination of effluent stream by liquid entrainment. Freezing problems in cold weather. Reduction in buoyancy and plume rise. Water vapor contributes to visible plume under some atmospheric conditions.
Electrostatic Precipitator	99+ percent efficiency obtainable. Very small particles can be collected. Particles may be collected wet or dry. Pressure drops and power requirements are small compared to other high-efficiency collectors. Maintenance is nominal unless corrosive or adhesive materials are handled. Few moving parts. Can be operated at high temperatures (550° to 850° F).	Relatively high initial cost. Precipitators are sensitive to variable dust loadings or flow rates. Resistivity causes some material to be economically uncollectible. Precautions are required to safeguard personnel from high voltage. Collection efficiencies can deteriorate gradually and imperceptibly.
Fabric Filtration	Dry collection possible. Decrease of performance is noticeable. Collection of small particles possible. High efficiencies possible.	Sensitivity to filtering velocity. High-temperature gases must be cooled to 200° to 550° F. Affected by relative humidity (condensation). Susceptibility of fabric to chemical attack.
Afterburner, Direct Flame	High removal efficiency of submicron odor-causing particulate matter. Simultaneous disposal of combustible gaseous and particulate matter. Direct disposal of non-toxic gases and wastes to the atmosphere after combustion. Possible heat recovery. Relatively small space requirement. Simple construction. Low maintenance.	High operational cost. Fire hazard. Removes only combustibles.
Afterburner, Catalytic	Same as direct flame afterburner. Compared to direct flame: reduced fuel requirements, reduced temperature, insulation requirements and fire hazard.	High initial cost. Catalysts subject to poisoning. Catalysts require reactivation.

Large-diameter cyclones are more efficient than settling chambers and have a wide range of efficiencies depending on the type of equipment used. They are best suited for particles in the 15- to 40-micron range; however, high-efficiency cyclones can collect particles in the 5-micron range. Tendency of the particles to agglomerate, forming larger sizes, eventually results in poor operation due to plugging or excessive accumulation on the walls of the equipment.

Multiple *small-diameter cyclones* are used on mechanical draft combustion units either as precleaners for electrostatic precipitators or as final cleaners.

Stack sprays (wet scrubbers) see some use in coal-fired boiler stacks for particulate control during soot blowing. Recently, a wet scrubber was installed on a pulverized coal-fired power plant, principally for sulfur dioxide control; however, it has the added benefit of removing particulates.

The collection efficiency of these devices is proportional to the energy input. And, since high-energy devices are expensive to install and operate, there has been a tendency to install wet collectors of limited efficiency.

For collection of dusts and fumes, a *baghouse* is preferred over a scrubber. A baghouse ensures virtually complete collection of almost any dust or fume, whereas only the best scrubbers ensure good collection efficiency. On the other hand, if mists of hygroscopic particles are present in the gas, then a scrubber is preferable to a baghouse.

Electrostatic precipitators are the most common gas cleaning devices. They have the highest efficiencies and the highest costs, thereby limiting their use on small combustion sources. They are also extremely sensitive to process changes. For instance, it has been established that low-sulfur fuels adversely affect the efficiency of precipitators designed for high-sulfur fuels. Advantages and disadvantages of electrical precipitation appear in Table 64.

Afterburners may be used, with high efficiency, to remove submicron odor-causing particulate matter.

Soot collectors are the only control devices that have found ready acceptance on coal-fired power plant boilers for controlling particulates during soot blowing. These devices collect only large particles (greater than 10 microns) during periods of soot blowing and are not designed to control the submicron particles responsible for opaque plumes.

2. Fuel Substitution and Modification

Particulate emissions from uncontrolled gas- and oil-fired power plants total 0.09 pounds per million BTU's input. Coal-fired plants equipped with high-efficiency (99.5 percent) electrostatic precipitators can emit even less, while hydroelectric and nuclear power plants are free of particulates. Table 65 illustrates relative particulate emissions resulting from various fuel usage.

When comparing substitution alternatives, allowance should be made for differences in heat requirements between seemingly identical applications.

Recent studies on the opacity of emissions from plants burning liquid fuels found that the fuels produced 0.2 to 1.2 micron-size sulfate ash particulates. The opacity of these plumes exceeded Ringlemann No. 2, and operation with supplementary natural gas was needed to reduce the opacity to acceptable levels. Only by using a premium low-sulfur, low-ash content liquid fuel were the plants able to produce a plume below Ringlemann No. 2.[354] Visible emissions standards as stringent as Ringlemann No. 1 are now being considered, which could seriously restrict the use of residual fuels in large boilers.

One of the major benefits of desulfurized fuels is that they will contain substantially lower amounts of ash and asphaltenes. North African residuals are low in both of those materials, and distillate flux (VGO) contains neither.

TABLE 65

COMPARISON OF ENERGY SUBSTITUTION ALTERNATIVES FOR ELECTRIC POWER GENERATION

Energy Substitution Alternative	Particulate Emissions lb/10^6 BTU input*
Hydroelectric	0
Nuclear	0
Gas (no control)	0.02
Oil (no control)	0.07
Coal--90% fly ash removal	0.67
Coal--99.5% fly ash removal	0.03

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* Based on emissions factors from Table 62 and the following gross heating values:

Coal--12,000 BTU/lb at 10-percent ash
Oil--150,000 BTU/gal.
Gas-- 1,000 BTU/ft^3.

Source: HEW, *Control Techniques for Particulate Air Pollutants*.

The effect of the reduction in ash content will be a reduction in deposits and corrosion on superheater tubes and particulate emissions. The lower asphaltene content will decrease the amount of carbon particles emitted to the stack. The tendency to form larger carbonaceous particles in the flue gas is minimized in large boilers, where the firebox temperature is high and residence time long, provided extra care is taken to ensure good fuel atomization.

Where flue-gas desulfurization processes are used in conjunction with solids recovery, the stack particulates should be at a minimum regardless of the fuel characteristics.

3. Heat Recovery

Better, more efficient use of the energy requirements of a process limits particulates by reducing the amount of fuel consumed. Good operating practice and proper design, installation, operation and maintenance are all key factors to efficient operation.

4. Relocation or Shutdown

Relocating a source of particulates obviously will not reduce the total particulate emissions; however, thorough consideration for protecting the environment should be given to the location of any new facilities.

Shutdowns may be necessary when air pollution levels threaten the public health or when abatement orders are ignored by a polluter.

5. Stack Dispersion

(Refer to the discussion under sulfur oxide controls, Section 1 of this chapter.)

Section 3.
NITROGEN OXIDE EMISSIONS AND CONTROL TECHNIQUES

A. Emissions

Emissions of man-made nitrogen oxides (NO_X) are mainly caused by combustion processes (see Table 2, "Summary of Sources, Concentrations and Major Reactions of Atmospheric Trace Gases," p. 21). SRI's estimated worldwide urban emissions of NO_X are shown in Table 66. Worldwide, over 50 percent of the total is due to coal burning, 42 percent to petroleum combustion, and 4 percent to natural gas burning. NAPCA's (now EPA's) figures suggest somewhat different percentages from stationary sources in the United States (see Table 67).

TABLE 66

WORLDWIDE URBAN EMISSIONS OF NITROGEN OXIDES (As NO_2)

Fuel	Source Type	Fuel Usage	Emissions Factor	NO_2 Emission
Coal	Power Generation	1,219 x 10^6 tons*	20 lb/ton†	12.2 x 10^6 tons
	Industrial	1,369 x 10^6 tons*	20 lb/ton†	13.7 x 10^6 tons
	Domestic/Commercial	404 x 10^6 tons*	5 lb/ton†	1.0 x 10^6 tons
Petroleum	Refinery Production	11,317 x 10^6 bbl*	6 ton/10^5 bbl‡	0.7 x 10^6 tons
	Gasoline	379 x 10^6 tons*	0.113 lb/gal†	7.5 x 10^6 tons
	Kerosine	100 x 10^6 tons*	0.072 lb/gal†	1.3 x 10^6 tons
	Fuel Oil	287 x 10^6 tons*	0.072 lb/gal†	3.6 x 10^6 tons
	Residual Oil	507 x 10^6 tons*	0.104 lb/gal†	9.2 x 10^6 tons
Natural Gas	Power Generation	2.98 x 10^{12} ft^3§	390 lb/10^6 ft^3†	0.6 x 10^6 tons
	Industrial	10.72 x 10^{12} ft^3§	214 lb/10^6 ft^3†	1.1 x 10^6 tons
	Domestic/Commercial	6.86 x 10^{12} ft^3§	116 lb/10^6 ft^3†	0.4 x 10^6 tons
Others	Incineration	500 x 10^6 tons	2 lb/ton†	0.5 x 10^6 tons
	Wood Fuel	466 x 10^6 tons¤	1.5 lb/ton†	0.3 x 10^6 tons
	Forest Fire	324 x 10^6 tons*	5 lb/ton#	0.8 x 10^6 tons
			TOTAL	52.9 x 10^6 tons

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* 1967 U.S. Statistical Abstracts.

† M. Mayer, *Pollutant Emission Factors* (HEW Public Health Service, May 1965).

‡ A. C. Stern, ed., *Air Pollution*, Volume II (New York, Academic Press, 1962).

§ Figure is 1.28 x U.S. usage as per 1967 U.S. Statistical Abstracts.

¤ World Forest Inventory, U.N. 1963.

\# R. J. Gerstle and D. A. Kemnitz, *Journal of the Air Pollution Control Association*, Volume XVII (1967), p. 324.

Source: HEW, *Control Techniques for Nitrogen Oxide Emissions from Stationary Sources*, NAPCA Publication No. AP-67 (HEW Public Health Service, Environmental Health Service, March 1970).

In every combustion process, the high temperatures at the burner result in the fixation of some oxides of nitrogen. These oxides are found in stack gases mainly as nitrogen oxide (NO) and to a lesser extent as nitrogen dioxide (NO_2). Nitrogen oxide will react to form NO_2 in the atmosphere at ordinary temperatures. Nitrogen oxides (NO and NO_2) concentrations in a flue gas may range from 10 to 3,000 ppm by volume, but average about 1,000 ppm. They are a function of the firebox temperature, design and operating conditions. The largest concentrations are found in gases from large combustion sources such as steam power plants, which are operated at high firebox temperatures. Combustion equipment of less than 20 million BTU/hr does not normally emit NO_X in concentrations above 100 ppm.[355] These larger sources are much more significant in the overall air pollution picture than the smaller domestic and commercial sources.

TABLE 67

NATIONWIDE NITROGEN OXIDES EMISSIONS--1968

Source	Emissions (10^6 Tons/Year)	% of Total
Transportation	8.1	39.3
Motor Vehicles	7.2	34.9
Gasoline	6.6	32.0
Diesel	0.6	2.9
Aircraft	N*	N
Railroads	0.4	1.9
Vessels	0.2	1.0
Non-highway Use of Motor Fuels	0.3	1.5
Fuel Combustion in Stationary Sources	10.0	48.5
Coal	4.0	19.4
Fuel Oil	1.0	4.8
Natural Gas†	4.8	23.3
Wood	0.2	1.0
Industrial Processes	0.2	1.0
Solid Waste Disposal	0.6	2.9
Miscellaneous	1.7	8.3
Forest Fires	1.2	5.8
Structural Fires	N	N
Coal Refuse Burning	0.2	1.0
Agricultural Burning	0.3	1.5
TOTAL	20.6	100.0

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* N=Negligible.

† Includes LPG and kerosine.

Source: HEW, *Nationwide Inventory of Air Pollutant Emissions 1968*, NAPCA Publication No. AP-73 (HEW Public Health Service, Environmental Health Service, August 1970).

Emissions of NO_x depend more on the amount of oxygen available in the firebox than on the ever-abundant presence of nitrogen. Therefore, at a given firebox temperature, NO formation increases as oxygen concentration increases. Multiple-port burners, in general, are associated with higher NO_x emissions than single-port burners.

Fuels producing higher flame temperatures also produce higher NO_x emissions. Thus, natural gas, fuel oil and coal will generally produce successively higher NO_x emissions, provided other conditions are constant. (This is not necessarily true for very large power plant boilers.) This order also happens to be that of increasing nitrogen content in the fuel. Emissions factors for NO_x from stationary sources are shown in Table 68.

TABLE 68

EMISSIONS FACTORS FOR NITROGEN OXIDES DURING COMBUSTION OF FUELS AND OTHER MATERIALS

Source	Average Emissions Factor
Fuels	
Coal	
Household and Commercial	8 lb/ton
Industry	20 lb/ton
Utility	20 lb/ton
Fuel Oil	
Household and Commercial	12-72 lb/10^3 gal
Industry	72 lb/10^3 gal
Utility	104 lb/10^3 gal
Natural Gas	
Household and Commercial	116 lb/10^6 ft^3
Industry	214 lb/10^6 ft^3
Utility	390 lb/10^6 ft^3
Wood	11 lb/ton
Combustion Sources	
Gas Engines	
Oil and Gas Production	770 lb/10^6 ft^3
Gas Plant	4,300 lb/10^6 ft^3
Pipeline	7,300 lb/10^6 ft^3
Refinery	4,400 lb/10^6 ft^3
Gas Turbines	
Gas Plant	200 lb/10^6 ft^3
Pipeline	200 lb/10^6 ft^3
Refinery	200 lb/10^6 ft^3
Waste Disposal	
Open Burning	11 lb/ton
Conical Incinerator	0.65 lb/ton
Municipal Incinerator	2 lb/ton
On-site Incinerator	2.5 lb/ton
Other Combustion	
Coal Refuse Banks	8 lb/ton
Forest Burning	11 lb/ton
Agricultural Burning	2 lb/ton
Structural Fires	11 lb/ton
Chemical Industries	
Nitric Acid Manufacture	57 lb/ton HNO_3 product
Adipic Acid	12 lb/ton product
Terephthalic Acid	13 lb/ton product
Nitrations	
Large Operations	0.2-14 lb/ton HNO_3 used
Small Batches	2-260 lb/ton HNO_3 used

Source: HEW, *Control Techniques for Nitrogen Oxide Emissions from Stationary Sources*.

A comparison between NO_x emission from coal, oil and gas on an equivalent BTU basis is shown in Table 69.

TABLE 69

AVERAGE NO_x EMISSIONS IN BOILERS AND POWER PLANTS
(Pounds $NO_x/10^9$ BTU)

Fuel	Household and Commercial	Industry	Electric Generation
Natural Gas (1,046 BTU/cu.ft.)*	111	205	373
Fuel Oil (149,966 BTU/gal)*	80-480	480	680
Coal (11,867 BTU/lb)*	337	842	842

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* Source: National Coal Association, *Steam Electric Plant Factors* (Washington, D.C., October 1968).

B. Control Techniques

Since the use of a nitrogen-free fuel does not prevent the formation of NO_x, effective controls must enter into the burning process of the fuel. Unfortunately for NO_x control, conditions which lead to high NO_x production have been deliberately chosen as desirable for the control of other air pollutants. High flame temperatures and excess air have been engineered into combustion processes as a means of controlling pollution from smoke, carbon monoxide and unburned hydrocarbons.

There are two specific areas in which established control technology for NO_x is available for commercial-scale use:

- Large oil- and gas-fired utility power plants may respond quite effectively to combustion modifications such as low excess air, two-stage combustion, flue-gas recirculation, steam or water injection, and combinations thereof. These treatments have the common effect of lowering the effective flame temperature.
- Pilot studies indicate that commercial processes for removing sulfur dioxide from flue gases by wet limestone (or other alkali) scrubbing can remove at the same time up to 20 percent of the NO_x present. It is not practical at present, however, to consider separate processes for the removal of NO_x and SO_x from combustion flue gases.

Table 70 summarizes NO_x control techniques for stationary combustion sources.

TABLE 70

CONTROLLING NITROGEN OXIDE EMISSIONS FROM STATIONARY SOURCES

Method	Remarks
1. Control NO_x emissions by combustion modifications	Potentially most attractive approach; limited experience shows relative simplicity and low cost.
a. Low excess air firing	a. Effective in reducing NO_x emissions from oil- and gas-fired power plant boilers. Major R&D effort required for application to pulverized coal-fired utility boilers--not practical for smaller pulverized coal applications.
b. Two-stage combustion	b. Effective for NO_x emissions control from oil- and gas-fired boilers. Pulverized coal firing presents engineering problems.
c. Combination of low excess air and two-stage combustion	c. Excellent results in NO_x emissions control in one application to a large gas-fired power plant. General applicability requires further demonstration.
d. Flue-gas recirculation	d. Laboratory results show sizable reductions in NO_x emissions particularly in combination with low excess air firing. Tests on boiler emissions inconclusive. Recirculation requires injection of flue gas directly into flame zone. Not simple, technically or economically.
e. Steam and water injection	e. Potential technique, similar to flue-gas recirculation. Based on principles of lowering peak flame temperature and dilution of combustion gases. Requires development, and may involve losses in efficiency.
f. Burner location and spacing	f. Design changes such as tangential firing can reduce NO_x emissions compared with front-wall firing in boilers.
2. Flue-gas treatment	Techniques used for flue-gas desulfurization, removes about 20% NO_x from flue gas.
3. Change fuel or energy source	
a. Switch to gas from oil and coal	a. Accepted emissions factors show decreasing order of NO_x emissions in burning coal, oil and gas. However, unusually severe operating conditions may give higher levels of NO_x emissions from gas than from oil.
b. Switch to paraffinic, low nitrogen containing fuel oil	b. Limited operating data show NO_x emissions reductions by about 50% compared with conventional fuel oil. Availability of paraffinic, low nitrogen containing fuel oil limits application.
c. Switch to nuclear generation	c. Nuclear electric generation is projected to grow. Additional hydroelectric generation potential is low. Essentially no NO_x is emitted.
d. Replace industrial, commercial household thermal requirements by remotely located central power with adequate NO_x emissions controls	d. NO_x emissions are intrinsically easier to control on a large scale, but thermal efficiency is much lower for conversion of fuel to electricity to heat than directly from fuel to heat.
4. Plant location and dispersion	
a. Relocate power plants to remote mine-mouth areas with long distance transmission to urban areas	a. Cost of high voltage transmission affects economic feasibility. Exposure of densely populated areas to NO_x emissions would be prevented.
b. Use tall stacks	b. Disperses NO_x in atmosphere to maintain lower ground-level concentration of pollutants, as long as atmospheric inversions do not interfere.

Section 4.
CARBON MONOXIDE EMISSIONS AND CONTROL TECHNIQUES

A. Emissions

Most atmospheric carbon monoxide is produced by the incomplete combustion of fuels used for transportation, power generation, industrial processing and space heating. No large natural source of carbon monoxide has been positively identified, but a number of geophysical and biological sources are known.[356]

The concentration of carbon monoxide in urban areas varies widely with time and location. Typical values ranging from 10 to 15 ppm have been reported in several metropolitan areas.[357] Carbon monoxide has long been considered an important pollutant, and for some time it was assumed that the only sources of carbon monoxide were combustion sources. Recent studies, however, have indicated some important natural sources of carbon monoxide.

Nationally, the quantity of carbon monoxide emissions from oil- and gas-fired stationary combustion sources is insignificant compared to the 100 million tons emitted from all sources. Even coal-fired sources are estimated at less than 1 percent of the total U.S. carbon monoxide emissions.

Carbon monoxide is formed when carbonaceous fuels are burned with insufficient oxygen. Low cooling rates and lean fuel-air mixtures will lower carbon monoxide emissions. The health effects of this pollutant have been documented in HEW's *Air Quality Criteria for Carbon Monoxide.*[358]

Emissions factors are used for estimating carbon monoxide emissions from various kinds of stationary combustion sources. However, the accuracy of the numbers used is insufficient for other than qualitative comparison of various fuels and equipment.

Although emissions factors indicate otherwise, it is not firmly established that there are differences between carbon monoxide emissions from coal-, gas- and oil-fired power boilers. It is quite probable that coal-fired stoker or grate-type commercial- or industrial-type combustion equipment emits more carbon monoxide per unit of heat input than oil- or gas-fired units of equivalent size, and it is firmly established that well-adjusted coal-fired units of domestic size emit more carbon monoxide than well-adjusted equivalent-sized oil- or gas-fired combustion equipment.

When coal-, oil- or gas-fired stationary combustion equipment is operated with insufficient air supply, carbon monoxide emission rates can be considerably greater than emissions from well-adjusted units. Under these conditions, oil-fired and coal-fired units emit dense smoke while maladjusted gas-fired equipment seldom emit visible smoke.

Data in Tables 71 and 72 illustrate that design can affect the quantity of carbon monoxide emissions. Carbon monoxide emissions factors are given in Table 73.

B. Control Techniques

For minimum carbon monoxide emissions, the combustion equipment should be designed for rapid reaction rates and long retention times. Various known techniques for carbon monoxide control[359] are discussed below.

1. Fuel substitution techniques include--
   - a. Switching to gas from oil or coal does not seem justified, since carbon monoxide emissions from boilers and furnaces are only a fraction of the total despite the fuel burned.
   - b. Switching to nuclear power would still produce some carbon monoxide, because of plant space heating requirements and the likelihood of

TABLE 71

CO EMISSIONS FROM SUSPENSION COAL-FIRED BOILER UNITS

Type of Firing	CO Emissions (lb/10^6 BTU)
Vertical	0.017
Corner	0.011
Front Wall	0.005
Spreader Stoker	0.029
Horizontally Opposed	0.044

Source: HEW, *Control Techniques for Carbon Monoxide Emissions from Stationary Sources*, NAPCA Publication No. AP-65 (HEW Public Health Service, Environmental Health Service, March 1970), p. 3-3.

TABLE 72

CO EMISSIONS FROM GRATE-FIRED COAL-BURNING UNITS

Type Unit	Unit Size (10^6 BTU/hr)	CO Emissions (lb/10^6 BTU)
Chain Grate	147	0.51
Spreader Stoker	59.2	<0.1
Underfeed Stoker	4.4	0.16
Underfeed Stoker	3.0	0.14
Underfeed Stoker	0.066	1.1
Hand-fired Stoker	0.115	3.5

Source: HEW, *Control Techniques for Carbon Monoxide Emissions from Stationary Sources.*

TABLE 73

CARBON MONOXIDE EMISSIONS FACTORS

Fuel Combustion--Stationary Sources	Emissions Factors
Coal	
Less than 10 x 10^6 BTU/hr capacity	50 lb/ton of coal burned
10 to 100 x 10^6 BTU/hr capacity	3 lb/ton of coal burned
Greater than 100 x 10^6 BTU/hr capacity	0.5 lb/ton of coal burned
Fuel Oil	
Less than 100 x 10^6 BTU/hr capacity	2 lb/1,000 gallons of oil burned
Greater than 100 x 10^6 BTU/hr capacity	0.04 lb/1,000 gallons of oil burned
Natural Gas	
Less than 100 x 10^6 BTU/hr capacity	0.4 lb/MMCF of gas burned
Greater than 100 x 10^6 BTU/hr capacity	Negligible lb/MMCF of gas burned

Source: HEW, *Control Techniques for Carbon Monoxide Emissions from Stationary Sources.*

standby power generating capacity employing conventional fuel, which would have to be periodically tested and operated.

c. Switching to hydroelectric power would have a similar effect as in *b* above.

d. Replacing space heating with central power would provide for easier carbon monoxide control since a larger installation is better equipped to control carbon monoxide. The expense of using electricity for space heating would hardly be justified on the basis of carbon monoxide reduction alone.

2. Plant relocation is rarely justified, for the same reasons as in *1.a* above.

3. Dispersion using tall stacks is used primarily in conjunction with other pollutants. For safety, it may be mandatory to reduce ground-level concentrations by the use of tall stacks.

4. Gas cleaning techniques are available that promote conversion of carbon monoxide to carbon dioxide or absorb carbon monoxide in amines and special copper liquors. However, no commercial-scale processes have been developed for cleaning carbon monoxide from stationary combustion source gases.

5. Good practice is the most sensible control technique.

a. A well-adjusted gas-fired boiler may emit less than 1 ppm of carbon monoxide but may emit more than 50,000 ppm (5 percent) if insufficient combustion air is supplied. Insufficient air always causes carbon monoxide formation and too much air may do the same. Proper fuel-air ratio adjustment is of major importance for reduction of carbon monoxide emissions from stationary combustion sources. Flue gases from the best-designed combustion unit may contain substantial concentrations of carbon monoxide if insufficient air is provided for combustion. Carbon monoxide emissions also increase when excessive air is admitted to cool combustion temperature below the optimum for maximum oxidation of fuel and carbon monoxide. As a rule of thumb, coal- and oil-fired units may be adjusted for 10- to 12-percent carbon dioxide on a dry basis, and natural-gas-fired units may be adjusted for 8- to 10-percent carbon dioxide on a dry basis. Since many units are designed to perform best at values outside these ranges, the combustion equipment manufacturer or other combustion experts should be consulted on proper fuel-air ratio adjustments for individual combustion units.

b. Firing in excess of the design rate is perhaps the greatest cause of carbon monoxide emissions from stationary combustion sources.

c. Short residence times tend to increase carbon monoxide in the flue gas due to less time for complete combustion. Proper residence time also allows the use of less excess air.

d. High temperature is desirable up to about 2,800 degrees Fahrenheit, where dissociation of carbon dioxide into carbon monoxide becomes noticeable. Rapid cooling and low oxygen concentration tend to hinder the recombination of carbon dioxide and thus increase carbon monoxide emissions.

e. The degree of atomization is of prime importance in the proper function of an oil burner.

Table 74 lists available oil burners and defects of operation which may result in carbon monoxide pollution. Proper maintenance by all concerned parties will be the best method of carbon monoxide control from these combustion sources.

In addition, two types of automatic combustion-control equipment are designed to minimize carbon monoxide emissions by--

- Automatically adjusting fuel supply under varying load demand
- Correcting and controlling the proper fuel-air ratio.

Section 5.
HYDROCARBON AND ORGANIC EMISSIONS AND CONTROL TECHNIQUES

A. Emissions

The principal sources of hydrocarbon (HC) emissions in the United States are: petroleum, 420 x 10^6 tons per year; coal, 565 x 10^6 tons per year; and natural gas, 420 x 10^6 tons per year.[360] Petroleum is the largest source since it is the chief fuel used in the internal-combustion engine.

Organic solvents are derived mainly from petroleum sources and are used in a variety of industries, such as chemical, drug and pharmaceutical. Rubber and plastic manufacturing also involves the use of organic-solvent-based adhesives. Paints, varnishes, lacquers and undercoatings are composed of 40- to 80-percent organic solvents which evaporate during and after application. Degreasing with solvents, like trichloroethylene, emits vapors which, in some cases, have proved fatal to humans. The dry cleaning industry emits solvent vapors. Vapors are emitted during the use of these solvents as well as in their manufacture.

Waste disposal by incineration, especially open burning, also contributes significant amounts of hydrocarbons.

Table 75 shows the relative contribution of various sources to the U.S. hydrocarbon emission total.

Table 76 is a tabular compilation of available emissions factors for hydrocarbons from various types of sources.

TABLE 74

CLASSIFICATION OF OIL BURNERS ACCORDING TO APPLICATION AND LIST OF POSSIBLE DEFECTS

Burner Type	Applications	Oil Type Usually Used	Defects Which May Cause Excessive CO Emission
Domestic			
Pressure atomizing	Residential furnaces, water heaters	No. 1 or 2	Increased viscosity of oil; nozzle wear; clogged flue, gas passes, or chimney; dirt clogging air inlet; oil rate in excess of design
Rotary	Residential furnaces, water heaters	No. 1 or 2	Increased viscosity of oil; clogged nozzle or air supply; oil rate in excess of design
Vaporizing	Residential furnaces, water heaters	No. 1	Fuel variations; clogged flue-gas passages, or chimney; clogged air supply
Commercial, Industrial			
Pressure atomizing	Steam boilers, process furnaces	No. 4, 5	Oil preheat too low or too high; nozzle wear; nozzle partly clogged; impaired air supply; clogged flue-gas passages; poor draft; overloading
Horizontal rotary cup	Steam boilers, process furnaces	No. 4, 5, 6	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue-gas passages; poor draft; overloading
Steam atomizing	Steam boilers, process furnaces	No. 5, 6	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue-gas passages; poor draft; overloading; insufficient atomizing pressure
Air atomizing	Steam boilers, process furnaces	No. 5	Oil preheat too low or too high; burner partly clogged or dirty; impaired air supply; clogged flue-gas passages; poor draft; overloading; insufficient atomizing pressure

Source: HEW, *Control Techniques for Carbon Monoxide Emissions from Stationary Sources.* NAPCA Publication No. AP-65 (HEW Public Health Service, Environmental Health Service, March 1970) p. 3-5.

TABLE 75

HYDROCARBON EMISSION TOTALS FROM STATIONARY SOURCES

Source	SRI's U.S. Annual Total* (Tons/Year)	U.S. P.H.S. Figures for 1968 (Tons/Year)
Coal	200,000	190,000
Fuel Oil	400,000	110,000
Residual Oil	100,000	
Kerosine	100,000	
Solvents	3,000,000	3,160,000
Incineration	5,000,000	1,480,000
Wood Burning	100,000	450,000
Forest Fires	200,000	2,180,000
Industrial Processes	no data	3,760,000
TOTAL	9,100,000	11,330,000

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* Calculated from SRI's worldwide estimates.

Source: HEW, *Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources*, NAPCA Publication No. AP-68 (HEW Public Health Service, March 1970).

TABLE 76

EMISSIONS FACTORS FOR HYDROCARBONS AND ORGANICS FROM STATIONARY SOURCES

Source	Emissions Factor (as CH_4)
Fuel Oil	
Less than 10 x 10^6 BTU/hr capacity	3 lb/1,000 gallons of oil
10 to 100 x 10^6 BTU/hr capacity	2 lb/1,000 gallons of oil
Greater than 100 x 10^6 BTU/hr capacity	0.8 lb/1,000 gallons of oil
Natural Gas	
Less than 10 x 10^6 BTU/hr capacity	Negligible lb/10^6 SCF of gas
10 to 100 x 10^6 BTU/hr capacity	7-64 lb/10^6 SCF of gas
Greater than 100 x 10^6 BTU/hr capacity	4-62 lb/10^6 SCF of gas
Dry Cleaning	
Chlor-hydrocarbons	1.7 lb/capita per year
Hydrocarbon vapors	2.2 lb/capita per year

Source: HEW, *Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources*. NAPCA Publication No. AP-68 (HEW Public Health Service, March 1970).

B. Control Techniques

This section will cover the methods now commercially employed to control the emission of organic air pollutants: (1) operational or process changes, (2) substitution of a higher boiling point material and/or a less reactive compound in the process, and (3) installation of control equipment to capture or destroy the organic vapors emitted from the process. By far, the most important technique for controlling air pollution is in the design of basic equipment to efficiently utilize or completely consume the processed materials. Failing this, control equipment should be used in order to reduce organic emissions.

1. General Classifications

Control techniques commercially available may be divided into five general classifications: incineration, adsorption, absorption, condensation and the use of nonphotochemically reactive materials.

a) Incineration

Incineration is the control of organic emissions by combustion. The objective is to oxidize completely the organic vapors and gases from a process or operation that emits them. Incineration devices have been widely used for reducing organic emissions, plus they offer the potential of heat recovery.

Afterburners are gas cleaning devices which use a furnace to burn (incinerate) organic emissions. Combustion is accomplished either by direct-flame incineration or by catalytic oxidation. Under the proper conditions, the firebox of a process heater or boiler may also be used as an afterburner. In many operations, afterburners reduce the amount of particulate matter present in the gas stream as well as the organic vapors, thereby reducing the visibility of the excess gas.

Properly designed and operated direct-flame afterburners usually achieve organic-vapor-removal efficiencies in excess of 95 percent. They require relatively little space and are simply constructed and easy to maintain, but fuel costs may be high.

Catalytic afterburners are designed much like direct-flame types but employ a solid active surface whereon the combustion reaction takes place, usually at a significantly lower temperature than would be required for combustion by direct flame. Since they can be operated at temperatures much lower than those required for direct-flame combustion, catalytic afterburners have the advantage of lower fuel costs. Their greatest use is in the control of solvent and organic vapors exhausted from industrial ovens.[361]

While catalytic incineration may appear overly attractive from certain economic viewpoints, several factors must be considered in specifying this type of control. Catalysts may require periodic cleaning to remove atmospheric dust and other ash-like materials resulting from the destruction of coating substances. Catalysts are also subject to poisoning or suppression by certain impurities such as halogenated compounds, phosphorus, silicon, mercury, arsenic, zinc and lead. Catalyst life, therefore, is variable and a function of the related process emissions. Some catalysts may last for as long as 20,000 operating hours, while others may have to be replaced within a year's time.[362]

In catalyst systems, preheating temperature and space velocity through the bed of the catalyst are important variables affecting efficiency. Efficiency capabilities of 85 to 92 percent have been reported for properly maintained catalyst systems.

The Los Angeles County Air Pollution Control District has probably had more experience with incineration than any other district or institution in the country. When Rule 66 was passed to control organic solvent emissions it stated that, if incineration was to be used, the control system must have an efficiency of not less than 90 percent. In response to questions concerning Rule 66, the Los Angeles County Air Pollution Control District published a series of questions and answers. Question 45 read as follows: "Is catalytic incineration a satisfactory method of complying with this rule?" Answer: "Any air pollution control equipment capable of reducing the organic materials to the required quantities is acceptable. The catalytic incineration devices that have been tested so far by the Air Pollution Control District are judged to be incapable of meeting the requirements of Rule 66." As a result of this experience, fume incineration equipment installed in Los Angeles to comply with Rule 66 have all been direct-flame systems.[363]

Pilot plant tests have shown that, when catalyst poisons can be avoided, the economic optimum abatement performance is obtained by combining incineration and catalytic oxidation. Better than 90-percent abatement was obtained at temperatures of 400 to 600 degrees Fahrenheit.

In some instances, the eye-irritating characteristics of gases has been more noticeable after a catalytic afterburner was installed. This is thought to be due to the partial oxidation of organic substances to aldehydes and organic acids and has been more apparent at operating temperatures below 900 degrees Fahrenheit. Little material causing eye irritation or odor has been emitted at equipment operating temperatures above 900 degrees Fahrenheit.[364]

Fireboxes of heaters and boilers can approximate the conditions of well-designed afterburners, provided the temperature, turbulence and flame contact are adequate. If the gas stream to be treated contains appreciable heat, special fireboxes (waste heat boilers) are used. Completely satisfactory adaptation of boilers for use as afterburners are not common. All aspects of the problem must be thoroughly evaluated before this method of air pollution control is used.[365]

b) Adsorption

There are two main types to consider: physical adsorption, where the gas is attracted to the surface of the adsorbent; and chemical adsorption, where the gas interacts with the adsorbent in the manner of a chemical reaction.[366]

Adsorption appears to be the most economic control method for organic vapors in the concentration range of 100 to 200 ppm when compared to other methods of emissions control.[367]

Activated alumina, silica gel and molecular sieves will preferentially adsorb water from a gas mixture containing water vapor and organic vapors. This seriously limits their use, since water vapor is present in many gas streams.

Activated carbon has the advantage to selectively adsorb organic vapors from gases, even in the presence of water vapor; therefore, they have been widely accepted. Another desirable feature is its ability to recover the adsorbed solvents on regeneration.

c) Absorption

From an air pollution standpoint, absorption has been used only to control inorganic compounds, rather than organic, because low concentrations of organic vapors tend to require a long residence time, resulting in use of very large quantities of absorbent.

Absorption of hydrocarbons is practiced in the petroleum industry as a manufacturing step and will not be covered in this section.

d) Condensation

This method has been proved many times to be a satisfactory control for vapor emissions. Many organic vapors, due to their high boiling points, will readily condense even when they are at low concentrations.

e) Use of Nonphotochemically Reactive Materials

Emission of organic air pollutants from many industrial operations cannot be reduced by the installation of control equipment. For example, solvent evaporation from architectural surface coatings cannot be confined for disposal. Industrial surface coating operations, vapor degreasing, dry cleaning, certain electronic and electrical manufacturing procedures, and some rubber and plastic manufacturing procedures emit organic vapors into the air which *can* be minimized by installing control equipment, but the cost may be prohibitive. An alternative to these "mechanical" techniques for controlling organic emissions from industrial operations is to reformulate the solvent being used so that the emitted material is less objectionable.

This distinction between solvent vapors which are classified as objectionable air pollutants and those which are not (or are much less offensive in this respect) is based on their "photochemical reactivity."

In processes which use chlorinated solvents, however, the control method is generally limited to adsorption, since the toxic effluent from incineration may require scrubbing. Due to the nature of cleaning and vapor-degreasing operations, more than 30 percent of solvent vapor loss is not captured by the exhaust systems, and it is very difficult to vent the entire system through a control device. The alternative method for complying is to substitute a less reactive solvent for the trichloroethylene. Several other solvents are available; namely, perchloroethane, 1,1,1-trichloroethane (methyl chloroform), 1,1,2-trichloroethane, trichloro-trifluoroethane and methylene chloride.

Most paint manufacturers and solvent suppliers have done considerable work to achieve paint and primer formulations meeting the requirements of Los Angeles' Rule 66. Evaluation of modified nonphotochemically reactive coatings and primers and results of testing have shown that substitute primers can be developed meeting requirements of the photochemically reactive material.

The problem of handling dilute streams with incineration has been helped by the Zorbcin process for concentration of the vapors from such streams. This process forces exhausted air through one or more activated-carbon beds to adsorb organic contaminants. The purified air is either discharged to the atmosphere or recovered. When the carbon bed becomes saturated with organic material, it is regenerated by circulating hot air through the bed. The hot air desorbs the emissions and builds up a higher concentration, so that a portion of the recirculating stream can be withdrawn and burned in an incinerator or catalytic combustion chamber.[368]

2. Dry Cleaning

There are two basic types of dry cleaning installations: those using petroleum solvents and those using chlorinated synthetic solvents (perchloroethylene).

The major source of hydrocarbon emissions in dry cleaning is the tumbler dryer through which hot air is circulated to dry the clothes. This drying produces vaporization of the solvent, which is emitted to the atmosphere unless controls are used.

Petroleum solvents generally were composed of 46-percent paraffins, 42-percent naphthenes and 12-percent aromatics. However, the advent of Los Angeles' Rule 66 has led to some reformulations so that the aromatic content is set below 8 percent.

Both adsorption and condensation systems may be used to control hydrocarbon emission from dry cleaning plants. Solvent recovery systems are commercially available and economically attractive for synthetic solvent plants. The main control equipment is a water-cooled condenser which can recover 95 percent of the solvent vapors released in the drying system.

Presently, there are no commercial condensing systems available to control solvent recovery in petroleum-based plants, because it is economically unattractive to recover the vapors. Recovering these vapors would necessitate additional equipment and costs. One recent estimate, however, indicates that despite the increased cost it could still remain competitive with synthetic plants.

Another control measure for the petroleum plants is through direct-fired afterburners.

3. Combustion Sources

Good operating practices are the most practical techniques for reducing hydrocarbon emissions from existing stationary combustion sources. Even the best equipment will perform poorly if improperly applied, installed, operated or maintained, and will result in the emission of hydrocarbons, smoke and other pollutants. Hydrocarbon emissions are directly related to the three common combustion parameters of time, temperature and turbulence. Thus, adequate combustion time, high temperature and a high degree of fuel-air turbulence will greatly reduce hydrocarbon emissions, increase combustion efficiency and reduce fuel consumption.

Hydrocarbon emissions may be reduced by upgrading combustion processes through improved designs that will reduce emissions or through a redesign that will reduce the quantity of fuel required for a given energy requirement.

Improvements in the combustion of coal in suspension and better mixing of highly turbulent secondary air into the primary combustion zone have improved combustion efficiencies and reduced emissions of hydrocarbons from steam-electric generating plants.

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Appendices

Appendix A

C
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Y

UNITED STATES
DEPARTMENT OF THE INTERIOR
OFFICE OF THE SECRETARY
WASHINGTON, D.C. 20240

April 15, 1969

Dear Mr. Abernathy:

One of the major national concerns today is the increasing pollution of our environment. Our increasing population, the growth of our cities and the expansion of our industry all create problems of air and water pollution. We feel it would be extremely useful and timely if the oil industry could present comments on the proper role of the industry in formulating or cooperating in corrective actions. A study and report by the National Petroleum Council would give the industry an opportuntiy to present proposals for the prevention or alleviation of pollution and would also serve as an indication of the willingness of the petroleum industry to cooperate with Governmental efforts in pollution abatement.

We, therefore, request that the National Petroleum Council undertake a study of air and water pollution by petroleum facilities and fuels and the impact of pollution control efforts on industry operations. We suggest that the study cover current pollution problems in the petroleum industry, measures for prevention of pollution in the petroleum industry, measures for counteracting accidents resulting in pollution of water by oil and the impact of pollution control regulations on the supply and cost of petroleum products and natural gas.

We are particularly interested in a study of the major disasters such as those which have resulted from tanker accidents and offshore well blowouts. We feel that the U.S. oil industry should be a leader in efforts to avoid or minimize these disasters since it plays such a predominant role in the operation of the facilities involved. This portion of the study should cover the frequency and causes of past accidents and the probability of future occurrences, the trends towards the use of larger facilities and the expected results of such trends, measures taken in the past to prevent or minimize such disasters, additional preventive and precautionary measures which might be taken, current research and suggested ideas for additional research for prevention and cleanup of pollution.

The study should also cover other sources of pollution in the petroleum industry. Specific areas are pollution from salt water flooding, waste oils, and storage and pipeline operations.

We also suggest that the study specifically cover the impact of environmental control regulations on the availability and cost of petroleum products and natural gas. This part of the study should include a careful analysis of regulations on raw material development, environmental controls and direct specifications on product properties.

In summary, we believe that this study should reflect efforts to assure that all pertinent facts are placed before the Government officials who are charged with the making of policy decisions involving pollution control regulations which may affect oil and gas operations.

Sincerely yours,

/S/ HOLLIS M. DOLE

Assistant Secretary of the Interior

Mr. Jack H. Abernathy
Chairman
National Petroleum Council
1625 K Street, N.W.
Washington, D.C. 20006

Appendix B

COORDINATING SUBCOMMITTEE
ON
ENVIRONMENTAL CONSERVATION--
THE OIL AND GAS INDUSTRIES

TASK GROUP I - STEERING TASK GROUP

CHAIRMAN

L. A. McReynolds, Director
Petroleum Products and
Environment Conservation
Phillips Petroleum Company

SECRETARY

Edmond H. Farrington
Assistant Director
National Petroleum Council

GENERAL EDITOR

Peter G. Kuh
Coordinator for Committee Studies
National Petroleum Council

* * * *

C. G. Cortelyou, Coordinator
Air and Water Conservation
Mobil Oil Corporation

Ernest Cotton, Advisor
Air and Water Conservation
Gulf Oil Corporation

P. N. Gammelgard
Senior Vice President
Public and Environmental Affairs
American Petroleum Institute

John M. Kelly
Independent Operator
Washington, D. C. 20036

R. C. Mallatt, Manager
Environmental Conservation
Standard Oil Company (Indiana)

H. H. Meredith, Jr.
Air and Water Conservation Coordinator
Humble Oil & Refining Co.

Dr. C. E. Moser
Assistant to the Vice President
Environmental Protection
Texaco Inc.

Cecil J. Olmstead
Vice President
Texaco Inc.

Note: Subcommittee members who are also Council members are ex-officio members of this Task Group.

Appendix B

COORDINATING SUBCOMMITTEE ON ENVIRONMENTAL CONSERVATION-- THE OIL AND GAS INDUSTRIES

TASK GROUP II - ENVIRONMENT TASK GROUP

CHAIRMAN

R. C. Mallatt, Manager
Environmental Conservation
Standard Oil Company (Indiana)

SECRETARY

Edmond H. Farrington
Assistant Director
National Petroleum Council

GENERAL EDITOR

Peter G. Kuh
Coordinator for Committee Studies
National Petroleum Council

* * * *

J. B. Ashton, Manager
Transportation and Supplies
Supply Forecast
Shell Oil Company

E. R. Heydinger
Manager, Economics Division
Marathon Oil Company

P. N. Gammelgard
Senior Vice President
Public and Environmental Affairs
American Petroleum Institute

H. H. Meredith, Jr.
Air and Water Conservation Coordinator
Humble Oil & Refining Company

Cecil J. Olmstead
Vice President
Texaco Inc.

COORDINATING SUBCOMMITTEE ON ENVIRONMENTAL CONSERVATION-- THE OIL AND GAS INDUSTRIES

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Dr. C. E. Moser
Assistant to the Vice President
Environmental Protection
Texaco Inc.

SECRETARY

Edmond H. Farrington
Assistant Director
National Petroleum Council

GENERAL EDITOR

Peter G. Kuh
Coordinator for Committee Studies
National Petroleum Council

* * * *

A. A. Cohn
Process Evaluation Engineer
El Paso Natural Gas Company

L. P. Haxby, Manager
Environmental Conservation
Public Affairs
Shell Oil Company

H. F. Elkin, Coordinator
Environmental Conservation
Sun Oil Company

Appendix B

COORDINATING SUBCOMMITTEE
ON
ENVIRONMENTAL CONSERVATION--
THE OIL AND GAS INDUSTRIES

TASK GROUP IV - WATER CONSERVATION TASK GROUP

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Ernest Cotton, Advisor
Air and Water Conservation
Gulf Oil Corporation

SECRETARY

Edmond H. Farrington
Assistant Director
National Petroleum Council

GENERAL EDITOR

Peter G. Kuh
Coordinator for Committee Studies
National Petroleum Council

* * * *

W. C. Brodhead
Vice President, Marine Department
Gulf Oil Corporation

T. H. Gaines, Coordinator
Air and Water Conservation
Union Oil Company of California

R. N. Simonsen, Consultant
Air and Stream Pollution
The Standard Oil Company (Ohio)

Dr. William R. Walton
Geological Research Director
Amoco Production Company

COORDINATING SUBCOMMITTEE
ON
ENVIRONMENTAL CONSERVATION--
THE OIL AND GAS INDUSTRIES

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CHAIRMAN

C. G. Cortelyou, Coordinator
Air and Water Conservation
Mobil Oil Corporation

SECRETARY

Edmond H. Farrington
Assistant Director
National Petroleum Council

GENERAL EDITOR

Peter G. Kuh
Coordinator for Committee Studies
National Petroleum Council

* * * *

Fred W. Batten
Senior Vice President
Columbia Gas System Service Corporation

S. D. Breitweiser
Executive Vice President, Refined Products
Cities Service Oil Company

J. A. Hatfield
Vice President - Operations
Plantation Pipe Line Company

J. L. Wilson
Vice President, Western Region
North American Producing Division
Atlantic Richfield Company

TABLE A

SUMMARY TABLE, WATER USE BY REFINERY CLASSIFICATION

Refinery Classification	A		B		C		D		E			
Operation	Topping		Topping and Cracking		Topping, Cracking and Petro-Chemicals		Topping, Cracking and Lube		Topping, Cracking, Lube and Petro-Chemicals		Total Refineries Reporting	
Refineries Reporting, No.	6		67		6		9		6		94	
MB/D Crude	94		3,296		587		1,163		1,206		6,346	
Average Raw Water Usage BW/BC	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Cooling	8.13	45.4	8.78	22.4	4.47	8.8	11.12	25.3	8.04	13.2	8.66	19.2
Processing	0.04	0.2	0.23	0.6	0.22	0.4	0.36	0.8	0.78	1.3	0.35	0.8
Steam	0.24	1.3	0.42	1.1	0.42	0.8	0.30	0.7	0.52	0.8	0.41	0.9
Total Raw Water	8.41	46.9	9.43	24.1	5.11	10.0	11.78	26.8	9.34	15.3	9.42	20.9
Average Reused or Conserved Water BW/BC												
Cooling Towers	9.42	52.5	27.11	69.2	38.41	75.0	28.84	65.6	47.02	77.3	31.99	71.1
Process Condensate	0.02	0.1	0.07	0.2	0.24	0.5	0.05	0.1	0.03	0.1	0.07	0.2
Steam Condensate	0.09	0.5	0.27	0.7	0.31	0.6	0.37	0.8	0.37	0.6	0.31	0.7
Miscellaneous	--	--	0.26	0.6	0.21	0.4	0.05	0.1	0.08	0.1	0.18	0.4
Air Cooling	--	--	2.05	5.2	6.89	13.5	2.90	6.6	4.02	6.6	3.00	6.7
Total Reused Water	9.53	53.1	29.76	75.9	46.06	90.0	32.21	73.2	51.52	84.7	35.55	79.1
Average Raw and Reused Water BW/BC												
Total Water Requirement	17.94	100.0	39.19	100.0	51.17	100.0	43.99	100.0	60.86	100.0	44.97	100.0

Source: R. V. Weil and G. F. Jackson, "Water Reuse Survey of Petroleum Refineries," presented at 20th Oklahoma Industrial Waste Conference, March 31, 1969.

TABLE B

SUMMARY TABLE, WATER USE BY REFINERY CAPACITY

Refinery Capacity, MB/D Crude	0-10		11-50		51-100		100+		Total Refineries Reporting	
Refineries Reporting, No.	6		47		24		17		94	
Total MB/D Crude	38		1,394		1,738		3,176		6,346	
Average Raw Water Usage (BW/BC)	No.	%	No.	%	No.	%	No.	%	No.	%
Cooling	5.48	17.3	6.05	18.6	7.56	18.5	10.44	19.7	8.66	19.2
Processing	0.09	0.3	0.18	0.6	0.23	0.6	0.50	0.9	0.35	0.8
Steam	0.56	1.7	0.37	1.1	0.37	0.9	0.45	0.9	0.41	0.9
Total Raw Water	6.13	19.3	6.60	20.3	8.16	20.0	11.39	21.5	9.42	20.9
Average Reused or Conserved Water (BW/BC)										
Cooling Towers	24.69	77.9	23.39	72.0	28.17	69.2	37.95	71.7	31.99	71.1
Process Condensate	0.48	1.5	0.09	0.3	0.12	0.3	0.03	0.1	0.07	0.2
Steam Condensate	0.34	1.1	0.32	1.0	0.16	0.4	0.38	0.7	0.31	0.7
Miscellaneous	--	--	0.13	0.4	0.41	1.0	0.08	0.2	0.18	0.4
Air Cooling	0.06	0.2	1.97	6.0	3.72	9.1	3.09	5.8	3.00	6.7
Total Reused Water	25.57	80.7	25.90	79.7	32.58	80.0	41.53	78.5	35.55	79.1
Average Raw and Reused Water (BW/BC)										
Total Water Used	31.70	100.0	32.50	100.0	40.74	100.0	52.92	100.0	44.97	100.0

Source: R. V. Weil and G. F. Jackson, "Water Reuse Survey of Petroleum Refineries," presented at 20th Oklahoma Industrial Waste Conference, March 31, 1969.

TABLE C

SUMMARY TABLE BY REFINERY CLASSIFICATION

	A	B	C	D	E	All Refineries
Raw Water--BW/BC						
Average	8.4	9.4	5.1	11.8	9.3	9.4
Minimum	0.7	0.3	1.1	1.4	2.5	0.3
Maximum	24.9	60.1	24.2	39.4	20.6	60.1
Reused Water--BW/BC						
Average	9.5	29.8	46.1	32.2	51.5	35.6
Minimum	0.0	0.0	15.4	0.2	18.6	0.0
Maximum	20.1	65.2	62.0	56.0	85.7	85.7
Total Water--BW/BC						
Average	17.9	39.2	51.2	44.0	60.8	45.0
Minimum	7.9	13.5	25.5	14.8	34.2	7.9
Maximum	25.0	67.0	72.5	58.1	88.2	88.2
Total Use--Raw Water Ratio (Total Water/Raw Water)						
Average	2.1	4.2	10.1	3.7	6.5	4.8
Minimum	1.0	1.0	1.5	1.0	2.2	1.0
Maximum	29.2	47.3	48.5	33.6	35.6	48.5

Source: R. V. Weil and G. F. Jackson, "Water Reuse Survey of Petroleum Refineries," presented at 20th Oklahoma Industrial Waste Conference, March 31, 1969.

Glossary

GLOSSARY

Absorption--the physical assimilation of one or more components of a gaseous or liquid phase into a second phase (liquid or solid) with the equilibrium distribution of absorbed material in the absorbent tending toward homogeneity, as contrasted to the surface phenomena of adsorption.

Acid Treating--the process of removing undesirable constituents of oils by contacting with sulfuric acid.

Additives--any materials incorporated in finished petroleum products for the purpose of improving their performance in existing applications or for broadening the areas of their utility.

Adsorption--the adhesion of molecules of gases or liquids to the surface of other bodies, usually solids, resulting in a relatively high concentration of the gas or solution at the point of contact.

Aerosol--a suspension of microscopic solid or liquid particles in air or gas, as smoke, fog or mist.

Afterburner--an auxiliary burner attached to the tailpipe of a turbojet engine for injecting fuel into the hot exhaust gases and burning it to provide extra thrust (also called tail-pipe burner).

Air Oxidation--oxidation of petroleum products such as asphalt or of spent chemicals for disposal by contacting with air at elevated temperatures.

Alkylation--a refinery process for chemically combining isoparaffinic with olefinic hydrocarbons. The product, alkylate, has high octane value and is blended with motor and aviation gasoline to improve the antiknock value of the fuel.

Amine--a class of organic compounds derived from ammonia by replacement of hydrogen with one or more univalent hydrocarbon radical.

Antiknock--the quality of a material to reduce autoignition knock in internal combustion engines.

Aromatic Hydrocarbons--hydrocarbons characterized by the pressure of a six-membered, unsaturated ring structure of carbon atoms. Examples include benzene, toluene and xylenes.

Ash--the amount inorganic, nonvolatile matter which remains after complete burning of a combustible material.

Asphalt--a brown to black solid or semi-solid bituminous substance occurring in nature, but also obtained as the residue from the refining of certain petroleums and then known as artificial asphalt.

Asphalt Cement--a refined asphalt, or combination of refined asphalt and flux, of suitable consistency for paving purposes.

Base Oils--refined or untreated oils used in combination with other oils and additives to produce lubricants.

Base Stocks (Gasoline)--a hydrocarbon fraction which makes up the bulk of a commercial gasoline. "Straight-run" and "cracked" gasolines are examples of a base stock. Smaller quantities of other hydrocarbons called "blending agents" or "blending components" are added to base stocks to produce a commercial gasoline.

Beaufort Scale--a scale, graded from 0 to 12, devised by Admiral Beaufort in the 19th century to indicate wind strength. Thus, zero on this scale represents a calm, 12 represents a hurricane, in which the wind velocity exceeds 75 mph. This scale has been adopted internationally.

Biochemical Oxygen Demand--the amount of oxygen utilized by organisms in the biochemical oxidation of organic matter in a waste water in a standard test procedure.

Biodegradable Detergents--detergents susceptible to destruction by bacteria, especially in sewage treatment plants.

Blending--mixing of components in predetermined and controlled quantities to give a product of desired and uniform quality.

Bottom Sampling--obtaining a sample by collecting a portion of material on the bottom of a container or pipeline.

Breathing Emissions--vapor emissions from the vent lines of petroleum storage facilities due to diurnal heating and cooling and to atmospheric pressure changes.

Carbon Residue--the amount of carbonaceous material left after evaporation and pyrolysis of an oil.

Casing--large steel pipes used to "seal-off" or "shut-out" water and prevent caving of loose gravel formations when drilling for crude oil. When set, drilling continues inside casing with a smaller bit. The overall length of this casing is called the *string of casing*. More than one string inside the other may be used in drilling the same well.

Catalytic Mufflers--an emissions control device designed to either catalytically oxidize the carbon monoxide and unburned hydrocarbons or catalytically reduce the nitrogen oxides in the exhaust from internal combustion engines.

Catalytic Reforming--a catalytic process to improve the antiknock quality of low-grade naphthas and virgin gasolines by the conversion of naphthenes (such as cyclohexane) and paraffins into higher octane aromatics (such as benzene, toluene and xylenes). There are about 10 commercially licensed catalytic reforming processes.

Caustic Washing--the processes of neutralizing oils with an aqueous solution of sodium hydroxide following acid treatment, or contacting hydrocarbon streams with alkaline treating solutions to extract acidic components.

Centrifugation--the process of separating two phases of differing density utilizing centrifugal force.

Cetane Number--a term expressing the ignition quality of a diesel fuel.

Charging Stocks--describes a product used to charge a still. It may be any product which has been recovered through previous distillation, such as gas oil, fuel oil or any product selected for further distillation or refining.

Chelating Agents--a metal deactivating additive that chemically combines with a metal to make it inactive. Especially useful where metals may be present in extremely small quantities.

Chemical Oxygen Demand--a measure of the oxygen equivalent required for oxidation by chemical means of organic and oxidizable inorganic matter present in a waste water.

Chemical Treating (Acidizing of a Well)--a technique for increasing the flow of oil from a well. Hydrochloric acid is introduced into the well to enlarge and reopen pores in oil-bearing limestone formations. An inhibited acid is used to prevent corrosion of the tubing. Pressure is applied to force the acid into the rock channels and pores, which causes their softer parts to become soluble. After a predetermined time, the acid is flowed or pumped out, leaving enlarged pores in the oil-bearing stratum. The acid attacks the limestone formation in all directions, and, amenable to the law of gravity, the downward pressure is greater than the lateral pressure, assuming equal density of strata. A blanket of calcium chloride or some other heavy inert liquid may be required at the bottom of the well to arrest the penetration of the acid downward to the saltwater level.

Christmas Tree--the assembly of pipes and valves at the top of the casing of an oil well that controls the flow of oil from the well.

Claus Process--the catalytic reaction of hydrogen sulfide with sulfur dioxide to yield elemental sulfur and water.

Cloud Point--the temperature at which paraffin wax or other solid substances begin to crystallize out or separate from solution when an oil is chilled under specified conditions.

Coke--the solid residue remaining after the destructive distillation of crude petroleum or residual fractions.

Compound--chemically speaking, a distinct substance formed by the combination of two or more elements in definite proportions by weight and possessing physical and chemical properties different from those of the combining elements.

Contaminant--any undesirable substance not normally present in a material or present in an excessive amount. Contaminants may alter either the physical or chemical properties of a material and thereby interfere with its desired usage.

Core Drilling--the act of taking a core. A core bit is attached to the end of the drill pipe; this tool then cuts a column of rock from the formation being penetrated; the core is then removed and tested for evidences of oil or gas, and its characteristics are determined. Coring tools permit the taking of full-hole cores, small-diameter cores and side-wall cores. Many wells are now cored all the way through potentially productive formations.

Corona Discharge--the discharge of electricity causing a corona; a luminous discharge from the surface of a conducting wire when voltage causes breakdown of surrounding air.

Cracking--a process carried out in a refinery reactor in which the large molecules in the charge stock are broken up into smaller, lower boiling, hydrocarbon molecules, which leave the vessel overhead as unfinished cracked gasoline, kerosines and gas oils. At the same time, certain of the unstable or reactive molecules in the charge stock combine to form tar or coke bottoms. The cracking reaction may be carried out with heat and pressure (thermal cracking) or in the presence of a catalyst (catalytic cracking).

Crankcase "Blowby"--engine combustion gases which because of pressure are forced past the proton rings and into the crankcase.

Cryogenic Fuels--fuels that must be maintained at extremely low temperatures to remain liquid; i.e., liquefied hydrogen, methane, propane, etc.

Cryogenic Storage--the low temperature storage of liquefied gases at atmospheric pressure.

Cutter Stock--a diluent material added to petroleum products to reduce viscosity, freeze point, etc.

Cycle Stock--unfinished product taken from a stage of refinery process and recharged to the process at an earlier step in the operation.

Deactivators--additives used to suppress undesirable chemical reactions in fuels and lubricating oils or to make another chemical inactive, such as by chelation.

Deasphalting--the process of removing asphalt from petroleum fractions, such as reduced crude. A common deasphalting process introduces liquid propane, in which the nonasphaltic compounds are soluable while the asphalt settles out.

Delayed Coking--a process in which the stock to be coked is rapidly heated to a high temperature and then charged to a coke drum where coking is effected by means of the contained heat. Delayed coking is designed to obtain the maximum yield of gas oil from the charge.

Desalting--removing calcium chloride, magnesium chloride and sodium chloride from crude petroleum.

Dessicant--a material such as calcium chloride, calcium sulfate, etc., for removing water from any given substance.

Desulfurization--the process for removal of undesirable sulfur or sulfur compounds from petroleum products, usually by chemical or catalytic processes.

Detergent--a substance having the properties of washing away undesirable substances through lowering of surface tension; wetting, emulsifying and dispersive action; foam formation. Soaps are natural detergents. In a lubricating oil, it is the property which prevents the accumulation of deposits in engine parts.

Detergent Additive--a substance incorporated in lubricating oils or motor gasolines to prevent formation of undesirable deposits.

Dilution--in motor oils in use, the contamination of oil in the crankcase with some of the less volatile portions of the fuel which have passed unburned into the crankcase.

Dimer--a molecule formed by the union of two identical olefinic molecules.

Diolefins--a type of open-chain, hydrogen-deficient hydrocarbons particularly receptive to oxidation, gum formation, and loss of octane rating during storage.

Dispersants--additives used to prevent lubricating oil impurities (usually oxidation products) from combining to form sludge; also, a material used to dissipate oil spills.

Distillation--the general process of vaporizing liquids, generally crude oil or one of its fractions, in a closed vessel while collecting and condensing the vapors into liquids.

Drilling Mud--a suspension, generally aqueous, used in rotary drilling and pumped down through the drill pipe to seal off porous zones and to counterbalance the pressure of oil and gas; consists of various substances in a finely divided state among which bentonite and barite are most common.

Dust--fine, dry particles of earth or other matter which may easily become airborne either by natural or man-made processes.

Emissions Factor--a statistical average of the rate at which air pollutants are emitted from the burning or processing of a given quantity of material.

Emulsification--the phenomenon of fine dispersion of one liquid held in suspension in a second liquid in which it is partly or completely immiscible.

Endothermic Fuels--fuels that absorb heat when thermally or catalytically cracked.

Filtration--the process of separating particulates from fluids by passing the combination through a filter media which retains the particulates.

Fixation--the act or process by which a fluid or a gas becomes or is rendered firm or stable in consistency, and evaporation or volatilization is prevented.

Flaring--the burning of volatile hydrocarbons in specially designed flares for safety purposes.

Flash--the lowest temperature at which vapors from a petroleum product will ignite momentarily on application of a flame in a standard test procedure.

Floating Roof-a special type of storage tank roof which floats upon the surface of the product in the tank, thereby eliminating tank breathing and reducing evaporation losses.

Flocculation--the gathering of suspended particles into aggregations; in drilling fluid a flocculating agent such as brine may cause the clay particles to flocculate with the result that the solids settle out.

Fluidized-Bed Combustion--the combustion of a material in a bed of finely divided solids maintained in a fluidized state by the combustion air flowing up through the bed at a proper velocity.

Fly Ash--fine solid particles of noncombustible ash with or without accompanying combustible particles carried out of a bed of solid fuel by the draft and deposited in quiet spots within a furnace and flues or within a boiler setting, or carried out of a chimney with the waste gases and often recovered for use as a constituent in commercial products.

Fog--vapor condensed to fine particles of water suspended in the lower atmosphere; formation is aided by presence of condensation nuclei such as dust particles.

Fractions--refiner's term for the portions of oils containing a number of hydrocarbon compounds but within certain boiling ranges, separated from other portions in fractional distillation. They are distinguished from pure compounds which have specified boiling temperatures, not a range.

Fuel Atomization--breaking up of fuel into a fine mist, so as to ensure good dispersion and combustion.

Fuel Oils--any liquid or liquefiable petroleum product burned for the generation of heat in a furnace or firebox or for the generation of power in an engine.

Fuel Substitution--the use of an alternative fuel type, instead of installing emissions control equipment, in order to comply with air pollution regulations.

Fume--a smoke, vapor or gas especially when noxious, offensive or irritating to the senses, as for example, exhaust fumes.

Gas Oil--a fraction derived in refining petroleum with a boiling range between kerosine and lubricating oil.

Gas Scrubbing--the removal of air contaminants in either a vapor or particulate state from an effluent gas stream by contacting the contaminated gas stream with a liquid absorbent.

Heat Sink--a mass used to absorb and retain heat. In jet aircraft the fuel may be used for this purpose.

Heating Oils--trade term for the group of distillate fuel oils used in heating homes and buildings as distinguished from residual fuel oils used in heating and power installations. Both are burner fuel oils.

Heavy Ends--the highest boiling portion of a gasoline or other petroleum oil.

Hydraulic Fracturing--method in which sand-water mixtures are forced into underground wells under pressure. This pressure splits the petroleum-bearing sandstone, thereby allowing the oil to move toward the wells more freely.

Hydrocracking--the cracking of a distillate or gas oil in the presence of a catalyst and hydrogen to form high-octane gasoline blending stocks.

Hydrogenation--a refinery process in which hydrogen is added to the molecules of unsaturated (hydrogen-deficient) hydrocarbon fractions. It plays an important part in the manufacture of high-octane blending stocks for aviation gasoline, and in the quality improvement of various petroleum products.

Hydrodesulfurization--the removal of sulfur from hydrocarbons by reaction with hydrogen in the presence of a catalyst.

Hydrotreating--the removal of sulfur from low-octane gasoline feedstocks by replacement with hydrogen.

Inhibitor--an additive which, when present in a petroleum product, prevents or retards undesirable changes taking place in the product, particularly oxidation and corrosion.

Ion Exchange--reversible exchange of ions contained in a crystal for different ions in solution without destruction of crystal structure or disturbance of electrical neutrality. The process is accomplished by diffusion and occurs typically in crystals possessing one or two dimensional channelways where ions are relatively weakly bonded. Also occurs in resins consisting of three dimensional hydrocarbon networks to which are attached many ionizable groups.

Isomerization--a process for altering the fundamental arrangement of the atoms in a molecule without adding or removing anything from the original material. In the petroleum industry, straight-chain hydrocarbons are converted to branched-chain hydrocarbons of substantially higher octane number by isomerization.

Isomers--in petroleum, different compounds composed of the same amounts of carbon and hydrogen but differing in physical properties owing to variation in molecular structure.

Kick--loss of normal fluid circulation caused by pressure from below in excess of that exerted by the drilling fluid being pumped into the well. If efforts to control a kick are unsuccessful and the subsurface pressure increases to the point where the expulsion of drilling fluid is violent and uncontrolled, a blow-out can and often does develop.

Killing the Well--to cease production from a well, usually for the purpose of converting it into an input or injection well.

Kinematic Viscosity--the absolute viscosity of a liquid (in centipoises) divided by its specific gravity at the temperature at which the viscosity is measured. See viscosity.

Knock--the sound, or "ping," associated with the autoignition in the combustion chamber of an automobile engine of a portion of the fuel-air mixture ahead of the advancing flame front.

LACT Unit (Lease Automatic Custody Transfer)--automatic measuring facilities in production leases where sustained accuracy of measurement is required for custody transfer or royalty assessment. Systems include gas and water separation equipment and may incorporate temperature compensation and BS and W monitoring.

Lead--petroleum industry parlance for any motor fuel antiknock additive containing lead.

Lead Susceptibility--the response of a gasoline, or gasoline fraction to the addition of lead antiknock additives as measured by the increase in octane number per increment of lead added.

Light Ends--the lowest boiling portion of a gasoline or other petroleum oil.

Liquefied Natural Gas (LNG)--natural gas which has been liquefied at a temperature of minus 258°F for ease of storage and transportation.

Liquefied Petroleum Gas (LPG)--as a rule, it is a mixture of natural and/or refinery gases reduced to a liquid and contained under pressure in steel cylinders. It is used as fuel for many different purposes, such as tractors, buses, trucks and stationary engines; for domestic and industrial purposes; and for power generation where commercial natural gas is not available. New uses are constantly being found. A recent development is the use of LPG as a direct quick-freezing agent in the frozen foods industry. It is also known and marketed as butane, propane, bottled gas, etc.

Lube Stocks--refinery term for fractions of crude petroleum of suitable boiling range and viscosity to yield lubricating oils when further processed and treated.

Mach Number--the ratio of the speed of a body through a fluid to the local speed of sound.

Magnetohydrodynamics--branch of physics that deals with magnetohydrodynamic phenomenon (of or relating to phenomena arising from the motion of electrically conducting fluids in the presence of electric and magnetic fields).

Mercaptans--organic compounds possessing a thiol group (-SH). The simpler mercaptans have a strong, repulsive, garlic-like odor which becomes less pronounced with increasing molecular weight.

Metal Deactivators--organic compounds which suppress the catalytic action of metal contaminants, usually by chelation, which may be contained in hydrocarbon distillates such as cracked gasolines and which tend to promote the formation of gum. These metal contaminants are usually either copper compounds which are retained in the gasoline as a result of copper sweetening or other catalytic metals with which the gasoline has come in contact during processing.

Methyl Ethyl Ketone (MEK)--colorless liquid obtained from petroleum derivatives; a component of a solvent used in dewaxing lubricating oils, also as a chemical intermediate; chemically, a four carbon atom straight chain molecule with an oxygen atom attached to the second carbon atom in the chain.

Microcrystalline Wax--a plastic, high melting point petroleum wax obtained by removing most of the oil from petrolatum by solvent extraction or other means.

Microstraining--the use of specially designed screening media having micron-size openings for the filtration of water streams to remove solid particles as small as 5 microns in size.

Mineral Oil--generally speaking, referring to the wide range of products derived from petroleum and within the viscosity range of products spoken of as oils.

Motor Gasoline--a volatile, liquid hydrocarbon fuel generally for use in the internal combustion engine, typically a blend of six to eight base stocks and additives to obtain proper qualities.

Motor Octane Number--an expression for the antiknock value of gasoline. Accepted as the guide of antiknock quality under high engine speed or heavy load conditions.

Naphtha--liquid hydrocarbon fractions, generally boiling within the gasoline range, recovered by the distillation of crude petroleum. Used as solvents, dry-cleaning agents and charge stocks to reforming units to make high-octane gasoline.

Natural Gas Liquids--hydrocarbons found in natural gas which may be extracted or isolated as liquefied petroleum gas and natural gasoline.

Neutralization--making neutral or inert, as by the addition of an alkali or an acid solution.

Nutrients--organic and inorganic materials required by microorganisms for normal growth.

Octane Number--a term numerically indicating the relative antiknock value of a gasoline. It is based upon a comparison with the reference fuels isooctane (100 octane number) and normal heptane (0 octane number). The octane number of an unknown fuel is the volume percent of isooctane with normal heptane which matches the unknown fuel in knocking tendencies under a specified set of conditions.

Octane Requirement--the minimum octane number necessary to operate a specific internal combustion engine without producing an audible knock.

Olefins--a class of unsaturated (hydrogen-deficient) open-chain hydrocarbons of which butene, ethylene and propylene are examples.

Oleophilic Agents--materials having an affinity for (wetted by) hydrocarbons, as contrasted to having an affinity for water.

Organic Solvents--ones having an organic source such as alcohols, ketones, esters, etc. When used as a lacquer solvent, it is known as an organic lacquer solvent.

Oxidation--the chemical reaction or process of combining substances with oxygen, generally taken from the air. All petroleum products are subject to oxidation.

Oxygen Demand--the oxygen-consuming characteristics of a waste water in a standard test. See Biochemical Oxygen Demand and Chemical Oxygen Demand.

Paraffin--a white, tasteless, odorless, chemically inert, waxy substance obtained from some petroleum oils.

Paraffin Distillate--a lubricating oil or heavy gas oil distillate fraction containing paraffin wax in a crystalline form.

Particle--a minute, discrete constituent of matter.

Particulate Matter--any matter, except water, that exists in a finely divided form as a liquid or solid.

Petroleum Industry--as used in this report, the term includes both the oil and gas industries.

Petroleum Solvents--ones derived by the distillation of crude oil of which naphtha is an example.

pH--the negative logarithm of the hydrogen-ion activity. It denotes the degree of acidity or of basicity of a solution. At 25° C, 7 is the neutral value. Acidity increases with decreasing values below 7, and basicity increases with increasing values above 7.

Phenol--a white crystalline compound composed of a benzene ring with an attached hydroxyl group used in the manufacture of phenolic resins, weed killers, solvents, synthetic detergents and chemical intermediates.

Photochemical Reactivity--a measure of the ability of a volatile organic material to participate in photochemical reactions to produce smog.

Photochemical Smog--an eye-irritating atmospheric condition resulting from a very complex series of chemical reactions involving reactive organic substances and nitrogen oxides and initiated by ultraviolet light from the sun.

Pollutant--any contaminant which when present in the air or water detracts or interferes with its desired usage.

Polymer Gasoline--a product of the polymerization of normally gaseous olefin hydrocarbons to form high-octane hydrocarbons in the gasoline boiling range.

Polymerization--the process of combining two or more simple molecules of the same type, called monomers, to form a single molecule having the same elements in the same proportion as in the original molecule but having different molecular weights. The product of the combination is a polymer. The combination of two or more dissimilar molecules is known as copolymerization. The product of this combination is a copolymer.

Pour Depressant, Pour Point Depressant--an additive which, when added to a wax-containing lubricating oil, reduces the solidification temperature of the oil.

Raffinate--in solvent refining, that portion of the oil which remains undissolved and is not removed by the selective solvent.

Reactivity Scale--a relative ranking of the ability of organic substances to participate in photochemical reactions.

Reference Fuel--a standard fuel used in testing performance quality of fuel products.

Refluxing--in fraction distillation, the return of part of the condensed vapor to the fractionating column to assist in making a more complete separation of the desired fractions. The material returned is reflux.

Reformate--the high-octane product from reforming a naphtha.

Reforming--the mild thermal cracking of naphthas to obtain more volatile products, such as olefins, of higher octane values; or catalytic conversion of naphtha components to produce higher octane aromatic compounds.

Research Octane Number--an expression for the antiknock rating of a motor gasoline; accepted as the guide to the antiknock qualities of fuels used in vehicles which are operated under mild conditions associated with low engine speeds.

Reserves--the quantity of mineral which is calculated to lie within given boundaries. It is described as total (or gross), workable or probable working, depending on the application of certain arbitrary limits in respect to deposit thickness, depth, quality, geological conditions and contemporary economic factors. Proved, probable and possible reserves are other terms used in general mining practice.

Residual Fuel Oils--topped crude petroleum or viscous residuums obtained in refinery operations. Commercial grades of burner fuel oils Nos. 5 and 6 are residual oils and include Bunker fuels.

Road Octane--a numerical value based upon the relative antiknock performance in an automobile of a test gasoline as compared with specified reference fuels. Road octanes are determined by operating a car over a stretch of level road or on a chassis dynamometer under conditions simulating those encountered on the highway.

RVP (Reid Vapor Pressure)--a method of measuring the vapor pressure of volatile hydrocarbons in a standard test procedure.

SAE Numbers--a standard classification of motor, transmission and differential lubricants by relative viscosity as developed by the Society of Automotive Engineers.

Saturated Hydrocarbons--a class of hydrocarbons containing the maximum ratio of hydrogen to carbon atoms and possessing no double or triple bonds.

Shear--rate of shear is the ratio of flow rate or velocity (of a lubricant) to the clearance between two parallel surfaces moving in opposite directions. For practical purposes shearing stress may be considered as the pressure to cause flow and rate of shear as the rate of flow.

Solvent--a substance, usually a liquid, capable of absorbing another liquid, gas or solid to form a homogeneous mixture.

Solvent Extraction--a process for separating compounds of approximately the same boiling points, but of different chemical types by employing solvents in which the solubilities of these compounds are widely different.

Sour--a hydrocarbon containing hydrogen sulfide or mercaptans, or a crude containing a large amount of sulfur.

Sour Water--waste water from refinery process operations which contains hydrogen sulfide.

Spent Chemicals--used process for treating chemicals which no longer possess sufficient reactivity for continued use in the desired application.

Stability--in petroleum products, the resistance to chemical change. Gum stability in gasoline means resistance to gum formation while in storage. Oxidation stability in lubricating oils and other products means resistance to oxidation to form sludge or gum in use.

Stocks--petroleum in storage, both crude and refined products; includes crude awaiting processing and products awaiting transfer to the point of utilization.

Stripper Well--a well which produces such small volume of oil that the gross income therefrom provides only a small margin of profit or, in many cases, does not even cover actual cost of production.

Sulfonates--a class of hydrocarbons resulting from the treating of oils with sulfuric acid and used as synthetic detergents, emulsifying and wetting agents, and chemical intermediates.

Surfactant--substances usually of the mixed nonpolar-polar type which impart emulsifiability, spreading, wetting, dispersibility or other surface-modifying properties.

Swabbing--the moving of a rubber swab, by means of a rope, up and down in the casing of a well.

Sweetening--the process of improving petroleum products in color and odor by converting the undesirable sulfur compounds into less objectionable disulfides or by removing them by contacting the petroleum stream with alkalies or other sweetening agents.

Synthetic Detergents--liquid or solid materials capable of dissolving oily materials and dispersing or emulsifying them in water. Petroleum sulfonates are examples of synthetic agents.

Synthetic Lubricants--a group of products, some of which are made from petroleum hydrocarbons, natural gas or refinery gases, which are used as oils or lubricating greases where heat, chemical resistance and other requirements can be better met than with straight petroleum products.

TCP, Tricresyl Phosphate $[PO(OC_6H_4CH_3)_3]$--colorless to yellow liquid used as a gasoline and lubricant additive and plasticizer.

TEL, Tetraethyl lead $[Pb(C_2H_5)_4]$--a volatile lead compound which is added in concentrations up to 3 cc. per gallon to motor and aviation gasoline to increase the antiknock properties of the fuel.

Thermal Pollution--the addition to an aquatic environment of waste heat in sufficient quantities to upset the natural balance of aquatic life.

Thiophosphates--lube oil additives formed by the combination of sulfur and phosphorus. Usually P_2S_5, phosphorus pentasulfide, sometimes called phosphoric sulfide, phosphorus persulfide or thiophosphoric anhydride. These additives are usually supplemented by more conventional additives, i.e., barium salts.

TML, Tetramethyl Lead $[Pb(CH_3)_4]$--a highly volatile lead compound added to motor gasoline to reduce knock. May be used alone or in mixtures with TEL.

Topped Crude--a residual product remaining after the removal, by distillation or other artificial means, of an appreciable quantity of the more volatile components of crude petroleum.

Topping--the distillation of crude petroleum to remove the light fractions only.

TOVALOP (Tanker Owner Voluntary Agreement Concerning Liability for Oil Pollution)--plan put into effect in 1969 by seven international oil companies, available to all tanker owners who wish to become participants. TOVALOP provides for reimbursement by participating ship owners to national governments at the rate of $100 per gross ton of tanker capacity up to $10 million, for expenses reasonably incurred by them to prevent or clean up pollution of coastlines as a result of the negligent discharge of oil from a participating tanker.

Trace Contaminants--impurities present in such small amounts that their presence and concentration can be determined only through use of highly sophisticated analytical techniques.

Trimer--a molecule formed by union of three simpler molecules of the same compound.

Turbidity--the state or condition of having the transparence or translucence disturbed, as when sediment in water is stirred up, or when dust, haze, clouds, etc., appear in the atmosphere because of wind or vertical currents.

Unsaturates--hydrocarbon compounds of such molecular structure that they readily pick up additional hydrogen atoms. Olefins and diolefins, which occur in cracking, are of this type.

Vacuum Distillation--distillation under reduced pressure, which reduces the boiling temperature of the material being distilled sufficiently to prevent decomposition or cracking.

Vapor Lock--a malfunctioning of carburetor and fuel feed system of motor vehicles caused by vaporization of light ends in the gasoline. Vaporization occurs when the temperature at some point in the fuel system exceeds the boiling point of the volatile light ends.

Vapor Pressure--the pressure exerted by the vapors released from an oil at a given temperature when enclosed in an airtight container. For motor gasoline it is a criterion of vapor-lock tendencies; for light products it is generally an index of storage and handling requirements.

Virgin Stock--oil processed from crude oil which contains no cracked material. Also called straight-run stock.

Visbreaking--lowering, or breaking, the viscosity of residuum by cracking at relatively low temperatures.

Viscosity--the measure of the internal friction or resistance of an oil to flow.

Viscosity Index (V.I.)-- a measure of the relative magnitude of viscosity changes in lubricating oils with changes in temperature.

Volatility--that property of a liquid which denotes its tendency to vaporize.

Wax--a term used loosely for any of a group of substances resembling beeswax in appearance and character and, in general, distinguished by their composition of esters of the higher alcohols and by their freedom from fatty acids.

Well Completion--in a potentially productive formation, the well must be completed in a manner to permit production of oil; the walls of the hole above the producing layer (and within it if necessary) must be supported against collapse, and the entry into the well of fluids from formations other than the producing layer must be prevented. A string of casing is always run and cemented, at least to the top of the producing layer, for this purpose. Some geological formations require the use of additional techniques to "complete" a well such as casing the producing formation and using a "gun perforator" to make entry holes, the use of slotted pipes, consolidating sand layers with chemical treatment, and the use of surface-actuated underwater robots for offshore wells.

Well Head--a structure built over the top of a well.

Well Stimulation--the use of secondary recovery methods such as water-flooding to increase the production rate of crude oil from a well or to prolong the useful life of the well.

Yield--in petroleum refining, the percentage of product or intermediate fractions obtained from the amount of crude oil charged to the processing operation.

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