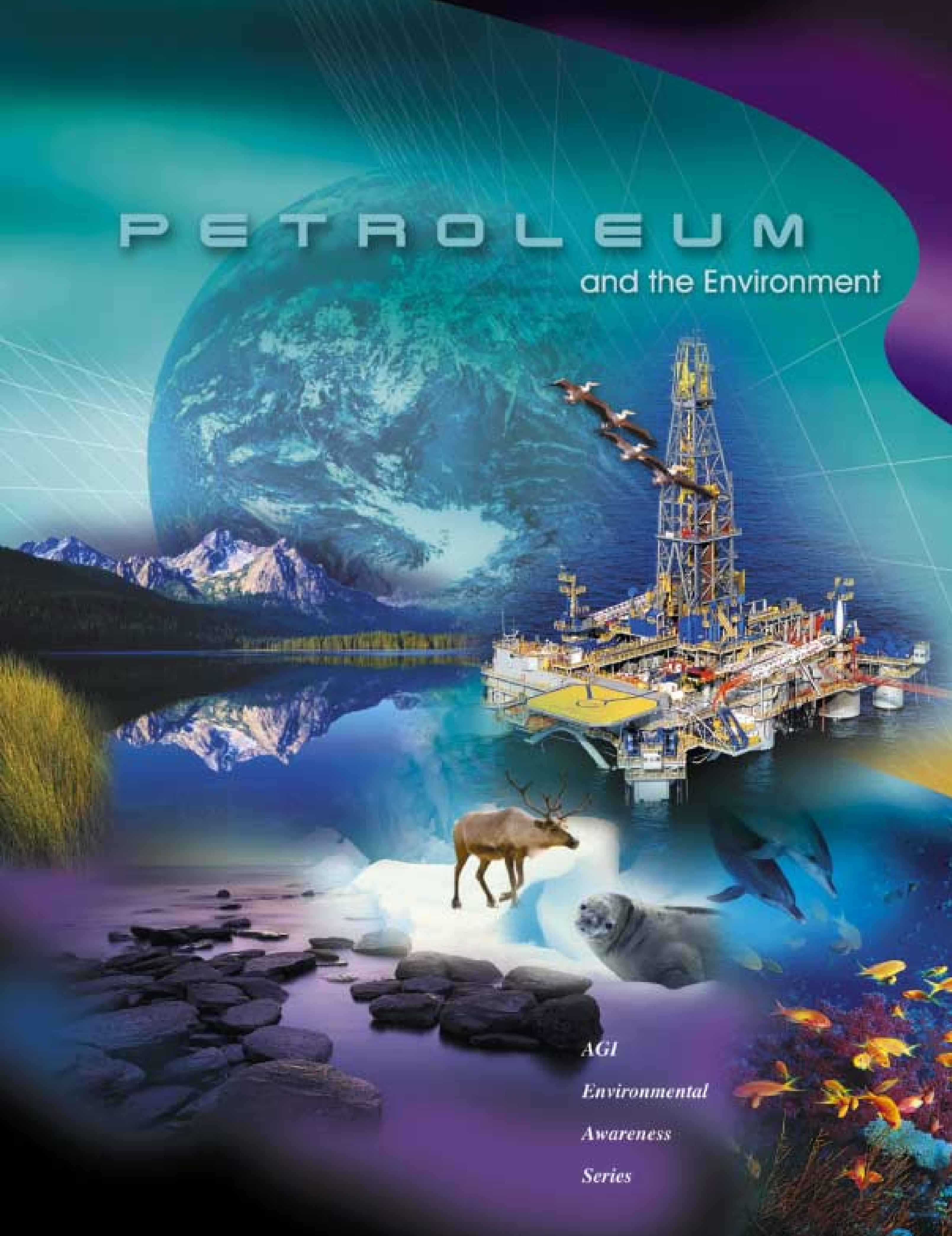
# PETROLEUM
## and the Environment



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AGI ENVIRONMENTAL AWARENESS SERIES, 6

# PETROLEUM and the Environment

William E. Harrison

Stephen M. Testa

*With a Foreword by Philip E. LaMoreaux*

**American Geological Institute**

*in cooperation with*

American Association of Petroleum Geologists Foundation, Bureau of Land Management, Minerals Management Service, USDA Forest Service, U.S. Department of Energy, U.S. Geological Survey

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# Contents



# Foreword

We live in the "age of petroleum." Nearly every newspaper has headlines regarding the value of North Sea crude, the energy crisis, the impact of Middle East oil on the U.S. economy and of greatest concern to all — "is our energy source being depleted?" The answer is yes. Coal, oil, and natural gas are essentially nonrenewable resources. Although we have abundant reserves of petroleum and have improved production methods, the cost of discovering and developing petroleum resources will continue to rise.

To paraphrase from *The Prize — The Epic Quest For Oil, Money, & Power*, by Daniel Yergin (Simon & Schuster, 1992), over the last century oil has brought out the best and the worst of our civilization. It is the basis of our industrial society. Of our energy sources, oil is the largest and has played a central role, owing to its strategic character, geographic distribution, the recurrent patterns of crisis in its search, discovery, production, and management, and also the irresistible temptation to gain its rewards.

Author Yergin, with amazing intuition, stated that oil would be tested again in our present generation by political, technical, economic, and environmental crises (Desert Storm and Iraq). The past century has been shaped and affected by oil. Creativity, ingenuity, technical confidence and innovation have coexisted with corruption, political ambition, and force. At the same time, oil has helped make possible mastery over the physical world, providing us in our daily lives with outstanding success in agriculture, manufacturing, transportation, food, clothing, medicine, and, literally, our daily bread.

Presidents in the past from both parties have promised self-sufficiency and an energy policy to provide our needs for the future. We have implemented gasoline conservation successfully, as new cars have become more efficient and the public has become more aware of the need for fuel economy with the "share the ride" and other programs. For over three decades, we have considered alternative energy sources such as solar, wind, and hydrogen, yet our development and consumption of these alternative sources represent only a fraction of one percent of U.S. energy used. We have rapidly expanded our use of petroleum and petroleum products. Thus, the U.S. has failed to come close to energy independence. We will remain in "the petroleum age" for at least for the foreseeable future and everyone must be aware that unless some very positive actions are taken, the U.S. can face another and even more serious problem of energy shortages as it did during the long pump lines of 1973 and 1974. The "age of petroleum" will remain with us for at least another twenty years and thus the importance for a better understanding of this resource by the public.

This Environmental Awareness Series publication has been prepared for a special reason — to give the general public, educators, and policy makers a better understanding of environmental concerns related to petroleum resources and supplies. The American Geological Institute produces this Series in cooperation with its 42 Member Societies and others to provide a non-technical geoscience framework considering environmental questions. *Petroleum and the Environment* was prepared under the sponsorship of the AGI Environmental Geoscience Advisory Committee with support of the AGI Foundation and the publishing partners listed on the inside front cover.

Philip E. LaMoreaux

*Chair, AGI Environmental Geoscience Advisory Committee*

# Preface

Many of us tend to take natural resources for granted. The use of petroleum and its products in this country is a good example. Over the last several decades, we've come to expect to be able to fill the gas tank whenever we wish, heat and cool our homes for personal comfort, and leave lights and computers on even when we're not using them. We enjoy these benefits at prices that make our country the envy of almost all of the other developed and petroleum-based economies in the world. Few of us ever think about petroleum as we're using common petrochemical products like a plastic cup or a plastic utensil. It usually takes increases in the price of gasoline, brownouts when electricity is in short supply, or an accident like an oil spill to focus our attention on petroleum and its impact on the environment.

Concerned citizens recognize the need to manage both our petroleum resources and natural environments wisely. This book, *Petroleum and the Environment*, provides an introduction to the major environmental issues associated with petroleum exploration, production, transportation, and use. New and innovative technologies continue to improve every aspect of petroleum operations including increased efficiency and effectiveness in exploration, production, refining, transportation systems, and environmental practices. Modern practices even incorporate aesthetic concerns, such as the visual impact associated with exploration and production activities. For example, production facilities are being designed to blend in with existing structures and environments. Advances in technology now allow development of oil and gas fields in sensitive ecosystems with minimal environmental disturbance, and industry is actively exploring for petroleum in water depths that were inaccessible just a few years ago.

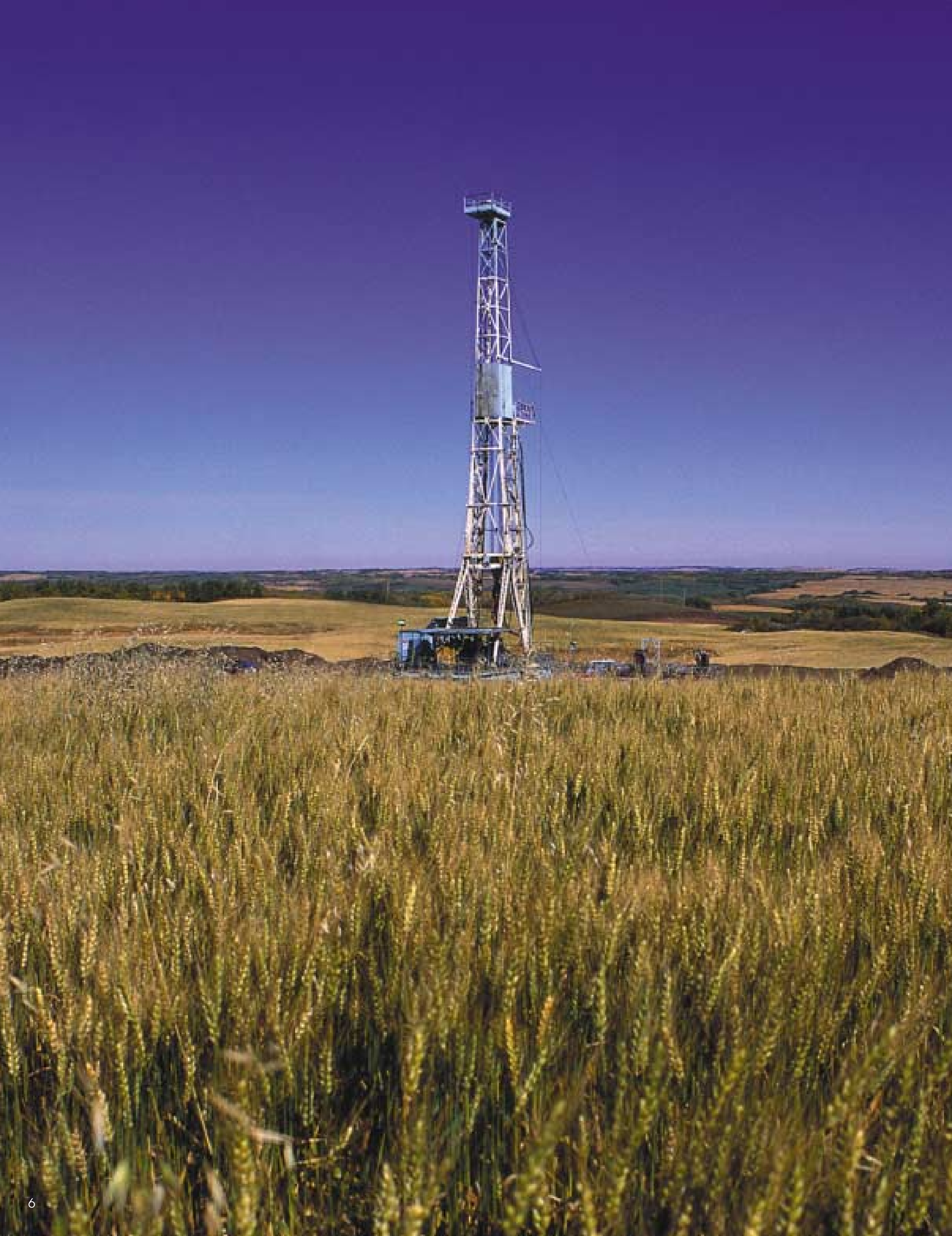
In spite of these advances, mitigating the environmental impacts associated with petroleum production and use still presents challenges. Concerns about how to deal with old facilities and abandoned oil fields raise environmental issues. In addition, the management of multiple, and often conflicting, uses of public land are commonly complex and controversial.

We hope that this book will help you understand petroleum — its importance, where it comes from, how it is processed for our use, the petroleum-related environmental concerns, the policies and regulations designed to safeguard natural resources, and global energy needs. We also hope this understanding will help prepare you to be involved in decisions that need to be made — individually and as a society — to be good stewards of our petroleum endowment and our living planet.

Without the assistance and counsel of many people this publication would not have been possible. We would especially like to thank Patricia Acker, Jennifer Sims, Mark Schoneweis, and John Charlton for their graphics contributions. Numerous individuals reviewed various drafts of the manuscript. Of these we would especially like to thank Jim Twyman, Frances Pierce, Dave Williams, Joe Curiale, Lee Gerhard, Marcus Milling, Phil LaMoreaux, Sal Block, Jim Handschy, Steve Zrake, and Travis Hudson. Julie Jackson and Julie DeAtley provided outstanding editorial and graphic design support to this project and we acknowledge their invaluable contributions to it. Finally, we would like to acknowledge the American Geological Institute and the publishing partners for their support.

William E. Harrison
Stephen M. Testa

*October, 2003*



# IT HELPS TO KNOW 1

Who would think that CDs, computers, crayons, rayon, nylon, plastics, furniture wax, antihistamines, liquid detergent, vitamin capsules, hair dyes, deodorant, paint, glue, sunglasses, and trash bags all originate from **petroleum** (Fig. 1)? Petroleum, the general term for naturally occurring compounds of hydrogen and carbon, literally means "oily rock" and includes crude oil and natural gas. After petroleum has been distilled and the impurities removed, it yields a range of combustible fuels, petrochemicals, and lubricants. In little more than 100 years, this remarkably useful natural resource has become a major source of energy and an economic foundation of society. However, supplies of petroleum, like many natural resources, are finite. As we attempt to chart a sustainable future on a planet with finite resources, it is important that citizens understand the environmental and conservation issues associated with petroleum development and use.

One of our objectives in writing this book is to help citizens understand the balance between the demand for affordable oil and natural gas to sustain modern standards of living and the requirements of environmental responsibility. As population increases, demands for petroleum and petroleum products will continue to increase even as we search for replacement energy sources.

New and innovative technologies continue to improve every aspect of the broad range of petroleum industrial operations including increased efficiency and effectiveness in exploration, production, refining, transportation systems, and environmental practices. Advances in technology now allow development of oil and gas fields in sensitive ecosystems with minimal environmental disturbance. Industry is actively exploring for petroleum in water depths that were inaccessible just a few years ago. In spite of these advances, mitigating the environmental impacts associated with petroleum production and use still presents challenges. Concerns about how to deal with old facilities and abandoned oil fields raise environmental issues. In addition, the management of multiple, and often conflicting, uses of public land are commonly complex and controversial.

***Oil and natural gas are forms of petroleum, a word that literally means "oily rock."***

| Product | Gallons per barrel |
|---|---|
| Gasoline | 19.4 |
| Distillate fuel oil *(includes both home heating oil and diesel fuel)* | 9.7 |
| Kerosene-type jet fuel | 4.3 |
| Residual fuel oil *(heavy oils used as fuels in industry, marine transportation and for electrical power generation)* | 1.9 |
| Liquefied refinery gas | 1.9 |
| Still gas | 1.8 |
| Coke | 2.0 |
| Asphalt and road oil | 1.4 |
| Petrochemical feedstocks | 1.1 |
| Lubricants | 0.5 |
| Kerosene | 0.2 |
| Other | 0.4 |
| | 44.6 |

*(Figures based on 2000 average yields for U.S. refineries.)*

## How Big is a Barrel?

*One barrel of crude oil contains 42 gallons. However, materials added during processing increase the total volume of products made from a barrel to 44.6 gallons of crude oil.*

## What the Environmental Concerns Are

Petroleum and its products, if not managed properly, can adversely affect the air we breathe, the water we drink, and the soils we depend on for growing food. The primary environmental concerns associated with petroleum are

- **Spills** — releases of petroleum or its products into the environment that can endanger habitat, wildlife, and people. Potential effects on surface water and groundwater are of major concern.
- **Waste disposal** — producing petroleum and processing its products creates various kinds of wastes that must be reused or disposed of in a responsible manner. For instance, proper disposal of used motor oil is essential.

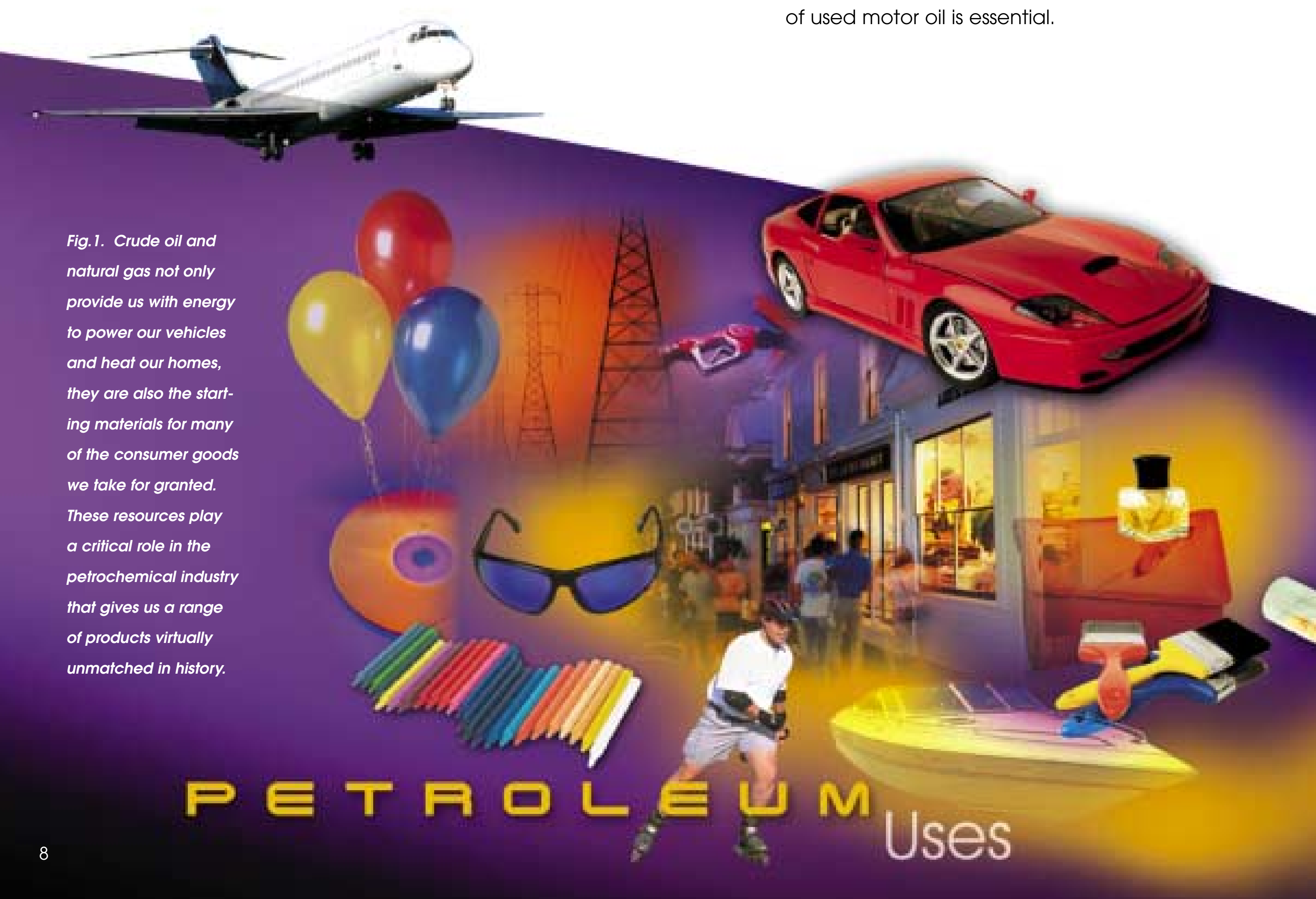



*Fig. 1. Crude oil and natural gas not only provide us with energy to power our vehicles and heat our homes, they are also the starting materials for many of the consumer goods we take for granted. These resources play a critical role in the petrochemical industry that gives us a range of products virtually unmatched in history.*

- **Emissions** — producing and using petroleum commonly results in emissions to the atmosphere that can create air-quality problems.
- **Safety** — petroleum and many of its products are highly flammable, and special guidelines must be observed to transport and use them safely.
- **Health** — some petroleum products are harmful to humans.
- **Visual and physical impacts** — petroleum operations, such as refineries and field production facilities, may be considered unsightly and can produce strong odors.

An extreme example of a large release of petroleum to the environment occurred during the 1991 Gulf War. Nearly half of Kuwait's 1,500 oil wells were gushing oil or set on fire. Wind-blown smoke plumes from the burning wells were visible from orbiting satellites (Fig. 2). These wells burned or spilled an estimated 60 million barrels of oil. A massive effort by fire-fighting teams from around the world brought these wells under control and helped minimize the quantities of oil that flowed from them. Releases of petroleum to such desert areas may not have the same impact that an accidental release would have if it occurred near a wildlife nesting or breeding area, for example. Some very sensitive environmental settings may take decades to fully recover from releases of petroleum.

## A Historical Perspective

Transportation fuel is, by far, the most common use of crude oil; our appetite for crude oil is directly related to the demand for fuels for automobiles, trucks, trains, and airplanes. The number of registered vehicles in the United States has grown steadily from about 50 million in 1950 to over 230 million in 2001. U.S. daily use of oil has more than doubled during the same period. In 1950, the


**a** *This satellite photo from February 1991 shows smoke plumes more than 200 km long from oil wells burning in Kuwait.*

**b** *Over 500 wells were set fire.*

**c** *Highly skilled firefighters capped wells like this one that continued to gush after the fire had been extinguished.*

*Fig. 2. Sabotoge of Kuwaiti oil fields during the Gulf War resulted in the largest oil spill in history.*

Fig. 3

## 2002 Petroleum Flow

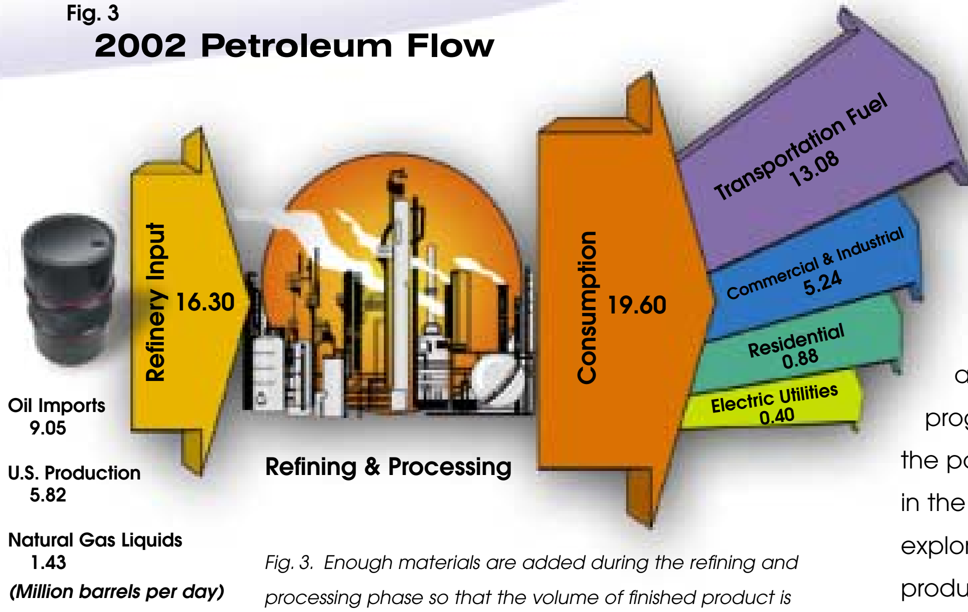



*Fig. 3. Enough materials are added during the refining and processing phase so that the volume of finished product is greater than the volume of original oil going in; 16.30 million barrels went into refineries each day in 2002 and approximately 19.60 million barrels of product were produced.*

United States used about 8.5 million barrels of petroleum every day; by 2001, daily consumption was over 19 million barrels (Fig. 3). The United States has been producing oil and gas for more than a century. Production from American fields reached its peak about 1970, and has been declining progressively since then. Almost all of the potential petroleum resource areas in the United States have been thoroughly explored. As a result, it is impossible for us to produce the quantity of petroleum we consume annually. Thus, almost every year we import more petroleum than the previous year, and today we rely on imported oil for over one-half of our needs (Fig. 4).

Although most people do not think in such terms, the U. S. daily consumption rate of 19 million barrels of petroleum products averages out to just over 3 gallons per day for every person or 12 gallons for a family of four. Sure, the gas nozzle goes into the family car every week or so, but do we ever stop to think that a four-person family actually uses about 12 gallons of oil a day?

Fig. 4a

## U.S. Oil Imports *(2002 Monthly Average)*

| *OPEC Countries* | Thousands of barrels per day | *NON-OPEC Countries* | Thousands of barrels per day |
|---|---|---|---|
| Algeria | 30 | Angola | 315 |
| Indonesia | 50 | Australia | 51 |
| Nigeria | 567 | Brazil | 57 |
| Qatar | 9 | Canada | 1,426 |
| Saudi Arabia | 1,521 | Columbia | 233 |
| United Arab Emirates | 16 | Ecuador | 99 |
| Venezuela | 1,195 | Gabon | 143 |
| | | Malaysa | 9 |
| | | Mexico | 1,490 |
| | | Norway | 335 |
| | | Russia | 86 |

*Source: US Dept. of Energy Information Administration*

Fig. 4b

## U.S. Oil Consumption, Production & Imports

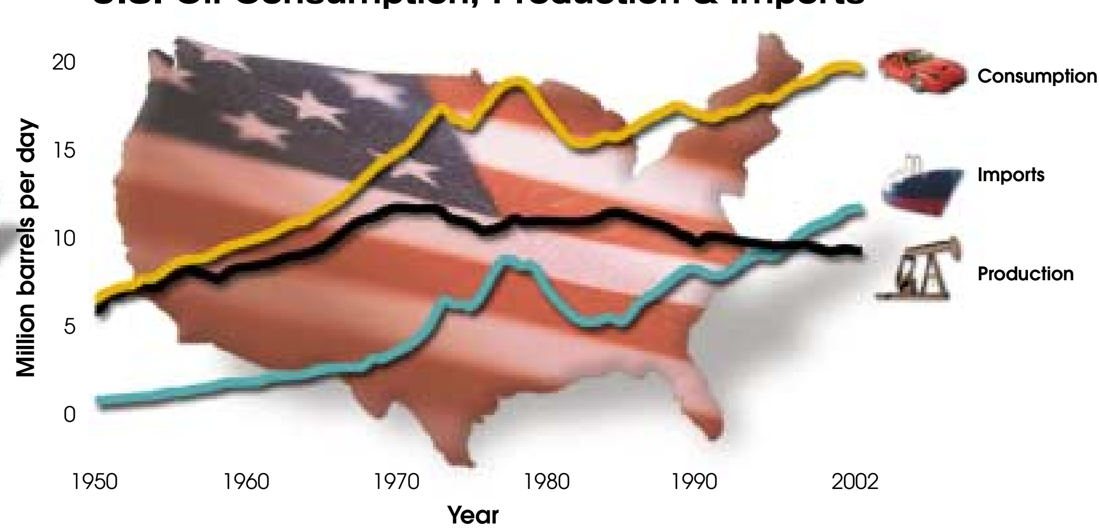



*Fig. 4. Oil consumption in the United States continues to rise. **(a)** In the late 1990s, we started importing more oil than we produced — a trend that is likely to continue. **(b)** Domestic production increased between 1950 and 1970 but has gone down since about 1985.*

Probably not. We certainly don't think about it in the same way we would if we bought 12 gallons of milk each day from the supermarket. Our high per capita consumption derives from the fact that petroleum is the low-cost source of energy and materials for many parts of our economy, not just the fuel for our family car. We have come to take such availability of energy for granted, and we rarely appreciate the extent that we have come to rely on petroleum.

Major U. S. reliance on petroleum products started as demand increased for energy. In 1854, Benjamin Silliman, a professor of geology at Yale University, entered into an agreement with a group of businessmen to conduct experiments to determine if the rock oil, which flowed into springs and salt wells in northwestern Pennsylvania, could be converted into a liquid that could be used in lamps. Based on Silliman's report in 1855, they formed the Rock Oil Company of Pennsylvania to explore the area for petroleum resources. These early efforts, along with work by a Canadian scientist, Abraham Gesner, established many of the concepts that provided the basis for future petroleum operations. Gesner built a kerosene refining plant in New York City and this, in turn, led to petroleum becoming an increasingly important energy source. In time, kerosene began replacing the coal that had been used for heating and the whale oil that had been used for lighting.

During the late 1800s, gasoline was an unwanted by-product of early kerosene production and was often dumped into pits and burned. Two technological developments of the early 1900s changed this situation: electricity and automobiles. The electric light bulb gradually replaced the kerosene lamp as a source of lighting, and Americans began buying automobiles powered by internal combustion engines. This new mode of transportation created a demand for the previously unwanted gasoline. Today, petroleum fuels virtually all of our transportation systems and provides about 60 percent of the energy we use in our homes and communities (Fig. 5). Although our high level of reliance on petroleum has developed in a short time, petroleum has a long history of use.

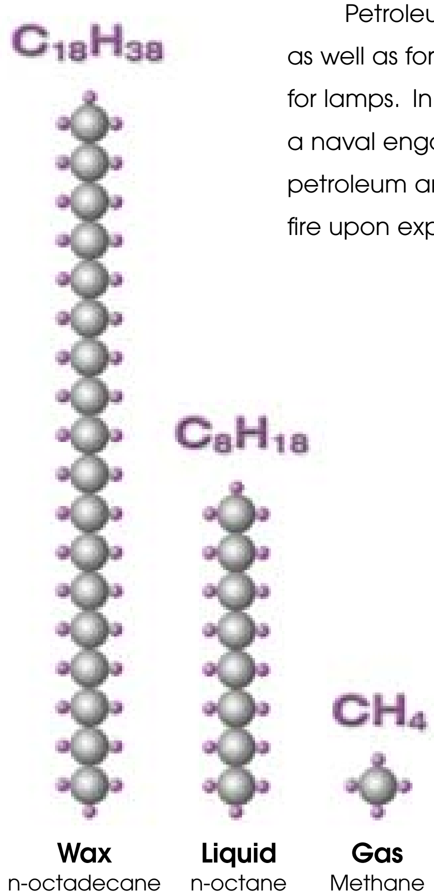
Natural seeps of oil and natural gas have been noted in the Middle East for thousands of years. Several oil-seep locations on the Euphrates River, which flows from Syria through Iraq and into the Persian Gulf, were noted in 3000 BC. The natural gas issuing from the seeps in Babylonia (the ruins are in southern Iraq) burned continuously for centuries and these fires were observed by the ancient Greeks and Romans. One of the most famous oil seeps in North America is the La Brea Tar Pit in California. Here oil comes to the surface and has done so for a long time as shown by the remains of now-extinct mammals, such as saber-tooth tigers, whose fossilized bones are recovered from these pits.

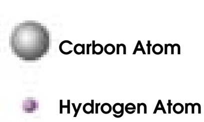
*Fig. 5. Technological developments of the early 1900s led to our current demand for petroleum to fuel our transportation and provide energy for our homes.*

In 600 BC, the Chinese produced natural gas and burned it to evaporate brine for salt recovery. This capability resulted from even earlier exploitation of the salt-rich subsurface brines, some of which were produced from great depths. By 900 AD, crude pipelines were made from bamboo and transported oil from producing wells to locations where it was used.

## Typical Hydrocarbons

*Fig. 6. The elements hydrogen and carbon are the principal components of crude oil and natural gas. Hydrocarbons vary dramatically in physical and chemical properties. Crude oil may contain hundreds of different hydrocarbons while natural gas consists of only a few.*




The use of degraded oil or asphalt from natural seeps to waterproof boats and as a binding agent in brick making also goes back thousands of years. The fiery burning seeps at Baku, the present capital of Azerbaijan, helped make that city famous for its abundant supplies of petroleum. Alexander the Great saw these `burning fountains' in the third century BC.

Archeologists and historians who study Middle Eastern cultures believe that there was a petroleum industry in 312 BC in the southern Dead Sea area. Large pieces of solid waxy bitumen would bob to the surface and men on reed rafts would paddle out quickly to take possession of them. The large chunks were chopped into smaller pieces for transport to Egypt where they were used for mummification and as a lubricant for moving large stones.

Petroleum was used in early warfare as well as for medical purposes and as fuel for lamps. In 680 AD, a historian described a naval engagement in which a mixture of petroleum and lime, which readily caught fire upon exposure to moisture, was used to destroy a fleet of ships in the Mediterranean Sea. Aerial firebombs called `naphtha pots' were used as incendiary devices in the battle for Cairo in 1167. In 1291, Marco Polo traveled through the Caspian Sea region, in what are now Georgia and Azerbaijan, and observed that petroleum was being commercially produced for medical purposes and as fuel for lamps.

Early European seafarers knew of the oil seeps in the West Indies and used the bitumen from these deposits to caulk their ships, and In the Western Hemisphere, people used asphalt to make waterproof coatings for their canoes.

Perhaps in the distant future, the $20^{th}$ and $21^{st}$ centuries will come to be known as the "Petroleum Era". It started about 100 years ago when kerosene replaced coal and whale oil, and it may continue for another 50 or 100 years until petroleum becomes scarce and is replaced by other energy sources. In the meantime, it is important for us to be sound stewards of Earth's petroleum, because it is a finite, nonrenewable resource.

## What Petroleum Is

Petroleum occurs in nature as a solid, liquid, or gas and consists primarily of hydrocarbons — compounds that contain only hydrogen and carbon (Fig. 6). In liquid form, petroleum can be a chemically complex mixture containing both hydrocarbons and minor amounts of other compounds that typically contain nitrogen, sulfur, and oxygen. Petroleum is remarkable for its wide range of physical and chemical properties. It can be a light-colored solid like candle wax, hard and black like bitumen in asphalt, or a colorless to straw-colored liquid that looks like water. One of the most common forms of petroleum is a dark syrupy liquid called crude oil, which is extracted from rocks underground, transported to a refinery, and then processed into a variety of products. The other common form of petroleum, natural gas, is odorless and colorless.

Did you know that some of the natural gas used in homes is generated and produced from our solid waste landfills? This gas is produced by bacterial decomposition of organic matter. Like crude oil, conventional natural gas is removed from subsurface rocks and then transported to locations to be used or processed.

## How Petroleum and Its Deposits Are Formed

Petroleum forms deep in the Earth when rocks containing sufficient amounts of organic matter are heated to suitable temperatures. **Petroleum source rocks** are rich in organic matter, mainly derived from the remains of microscopic organisms that lived in ancient oceans or lakes. When organisms died, they settled to the seabed (or lakebed) where they were buried with sand and mud. The organic matter, biochemicals or degraded biochemicals, of these organisms eventually become incorporated into rocks such as **shale** (Fig. 7). The chemical reactions that convert the organic matter in shale into petroleum require heat. A special type of organic-rich rocks, called **'oil shale'**, contain enough organic matter to yield over 30 gallons of petroleum for every ton (a ton of shale is a cube that is approximately 29 inches on each side) heated to about 1000° F. Many petroleum source rocks have been buried so deeply that the natural heat in the Earth has generated oil and gas from them. The petroleum that these rocks produce is buoyant. If **permeable** conduits are available, petroleum will migrate upward and away from its source rocks. In fact, unless petroleum is trapped underground in reservoir rocks, it will migrate to the surface and form natural **seeps** (Fig. 8).

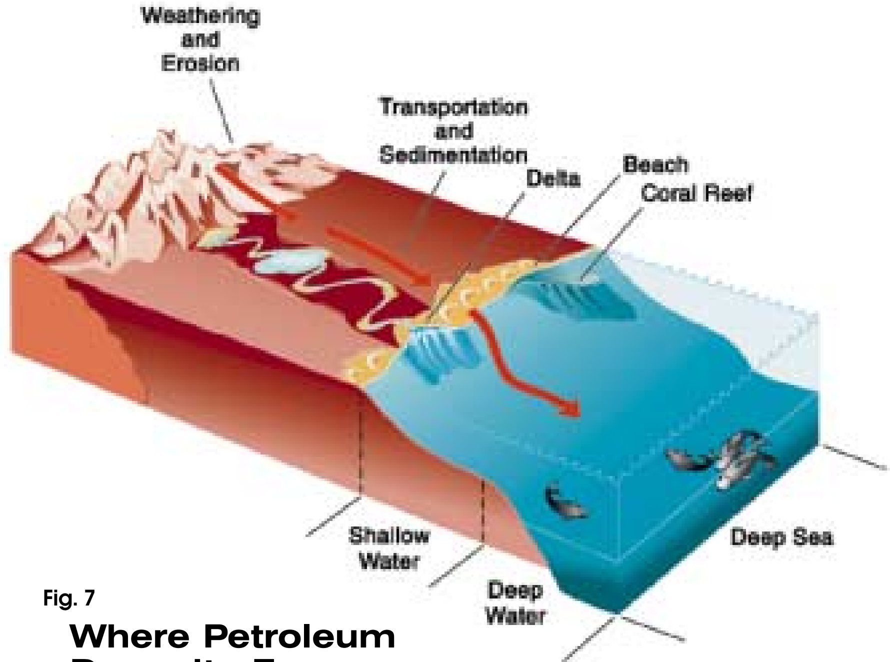



**Fig. 7**

## Where Petroleum Deposits Form

*Fig.7. Petroleum deposits almost always occur in sedimentary rocks that have developed from particles deposited in marine basins. The size of the particles and the velocity of streams carrying them help determine the kind of sedimentary rocks to be formed. Conglomerate, sandstone, and limestone are all potential reservoir rocks because they can be porous enough to store petroleum.*

Petroleum doesn't accumulate in underground lakes or rivers; it exists in tiny spaces (voids) in subsurface rocks (Fig. 9). **Reservoir rocks** contain interconnected voids that will allow fluids, such as petroleum and water, to flow through the reservoir. As a result of its buoyancy and pressure conditions in the Earth's crust, petroleum gradually migrates towards the surface. This upward movement stops when petroleum encounters a barrier, such as a layer of impermeable rock. The combination of porous

*Fig. 8. Natural oil seep in Wind River Canyon, WY.*

**natural oil seep**

# Underground Oil and Natural Gas Reservoirs

Fig. 9

## Reservoir Rocks

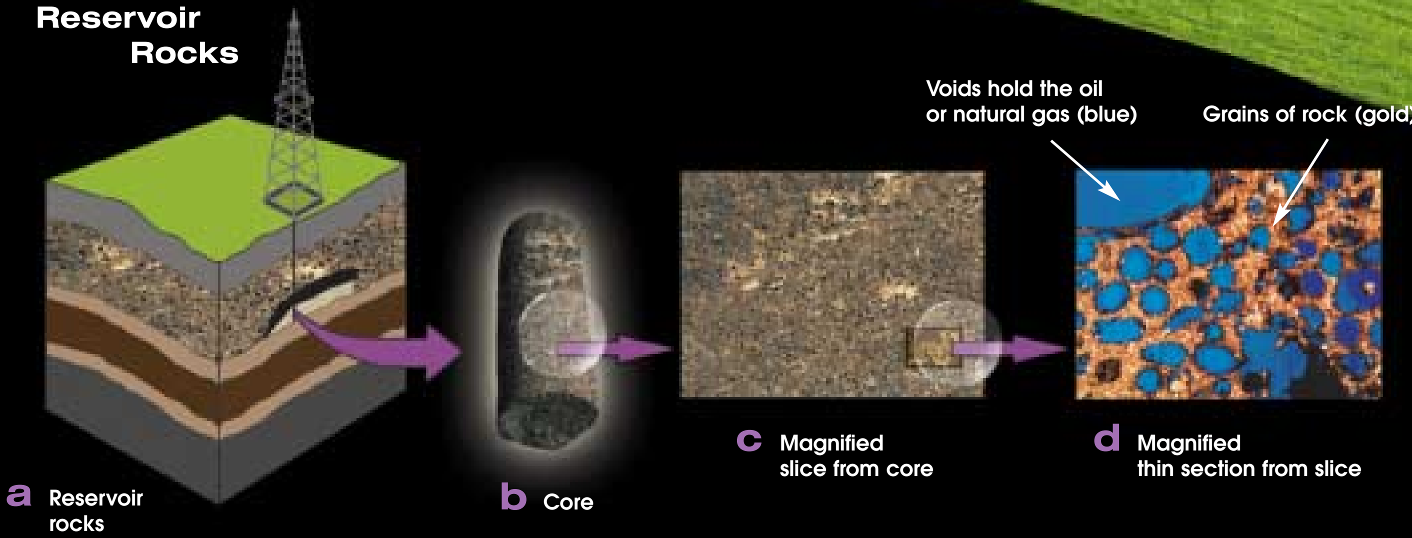
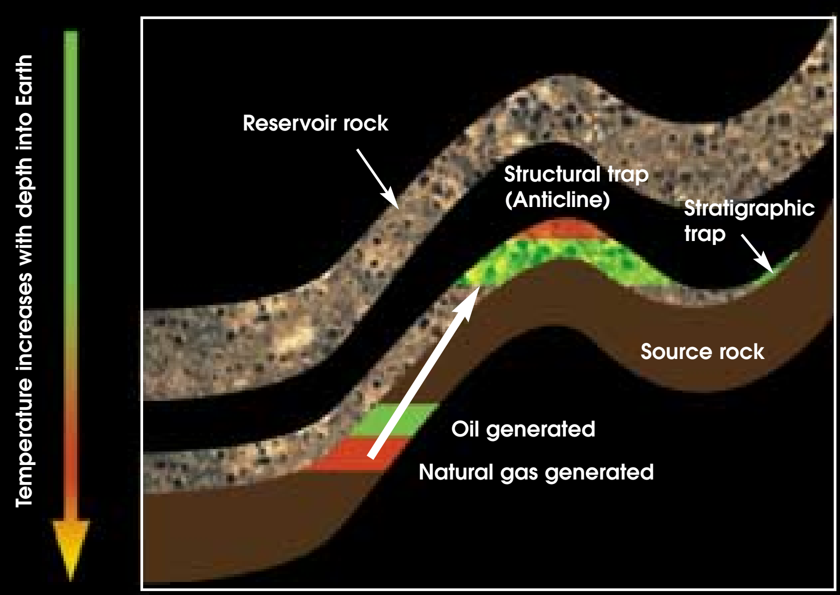



*Fig.9. (a) Limestone and sandstone are sometimes porous enough to become Earth's underground reservoirs for oil and natural gas. (b) A rock core was taken from a depth of a few thousand feet. (c) A small piece cut from the core was ground so thin (to the thickness of a piece of paper) that light passes through it. (d) Magnification of this "thin section" exposes the tiny spaces (blue) where oil and gas are stored among the grains of rock (gold).*

Fig. 10

## Trapping Hydrocarbons

*Fig. 10. Petroleum exploration efforts focus on finding traps, geologic features that contain an accumulation of oil or natural gas. Organic rich rocks release petroleum, as they become deeply buried in the Earth and are exposed to high temperature conditions. The petroleum rises until it is "trapped". Porous and permeable reservoir rock that is capped by an impermeable layer creates a trap that prevents the oil and gas from moving laterally. A structural trap results from the buckling or bending of rock layers. A stratigraphic trap occurs where porosity (holes in rocks) and permeability (a measure of how readily fluids can move through rocks) are so low that petroleum cannot continue to move.*



reservoir rock to hold petroleum topped by an impermeable layer that serves as a seal and barrier to further migration creates a geologic feature called a **trap** (Fig. 10). Because subsurface traps are primary sources of crude oil and natural gas accumulations, they are the ultimate target of petroleum exploration programs.

## Where Petroleum Occurs

Almost all of the petroleum known in the world comes from rocks that were formed in ocean basins or in **sedimentary basins** on continents — depressions in the surface of the Earth where layers of sand, silt, clay, or limestone accumulate and form sedimentary rocks (Fig. 11). Sedimentary basins that contain petroleum may be geologically young — just a million or so years — or quite old. Some oil-rich basins in California are only a few tens of millions of years old, but petroleum is also produced from sedimentary basins that are many hundreds of millions of years old. Examples in the United States include major producing regions like the North Slope of Alaska, mid-continent area, Gulf of Mexico, and West Texas. Although many sedimentary basins occur in the United States, they don't all contain oil or natural gas. Petroleum is produced where it can be economically recovered. It is produced in 35 of the 50 states, in cities like Los Angeles and Oklahoma City, and in places such as the North Slope of Alaska and the Rocky Mountains.

Depth and temperature are two of the major factors controlling the distribution of oil and gas fields in a sedimentary basin. When oil is subjected to increasing temperatures at greater depths, it breaks into progressively smaller molecules until it is completely converted to natural gas. Thus, the chances for preserving liquid petroleum decrease as depth and temperature increase. Methane, the primary constituent of natural gas, is the lightest, least complex hydrocarbon. Methane also has the greatest thermal stability of any hydrocarbon and is unlikely to be destroyed, even at very high basin temperatures. The temperature at the bottom of a 25,000-foot exploration well can be over 400° F, and only natural gas would be expected at these depths and temperatures.

Virtually every sedimentary basin in the world is potentially capable of containing some petroleum, but very large accumulations are rare. They have been found in only a few areas, such as the Middle East, Alaska, Central and South America, West Africa, and the North Sea. Recent technological developments allow us to produce petroleum and natural gas from polar to equatorial settings and in offshore areas where water depths exceed a mile. The most important implication of the uneven but geographically wide distribution of petroleum is that it must be transported safely from the point where it is produced to the place where it will be processed or used.

North America contains only 6 percent of the world's current oil reserves. Because most parts of the United States have been extensively explored, we have already produced much of our known oil and natural gas reserves. Although domestic oil has been produced from 35 states, over 80 percent of our remaining reserves are in Texas, Alaska, California, and Louisiana. Since the late 1990s, U.S. production has not kept pace with demand, and now we import more oil than we can produce domestically (Fig. 4, p. 10).

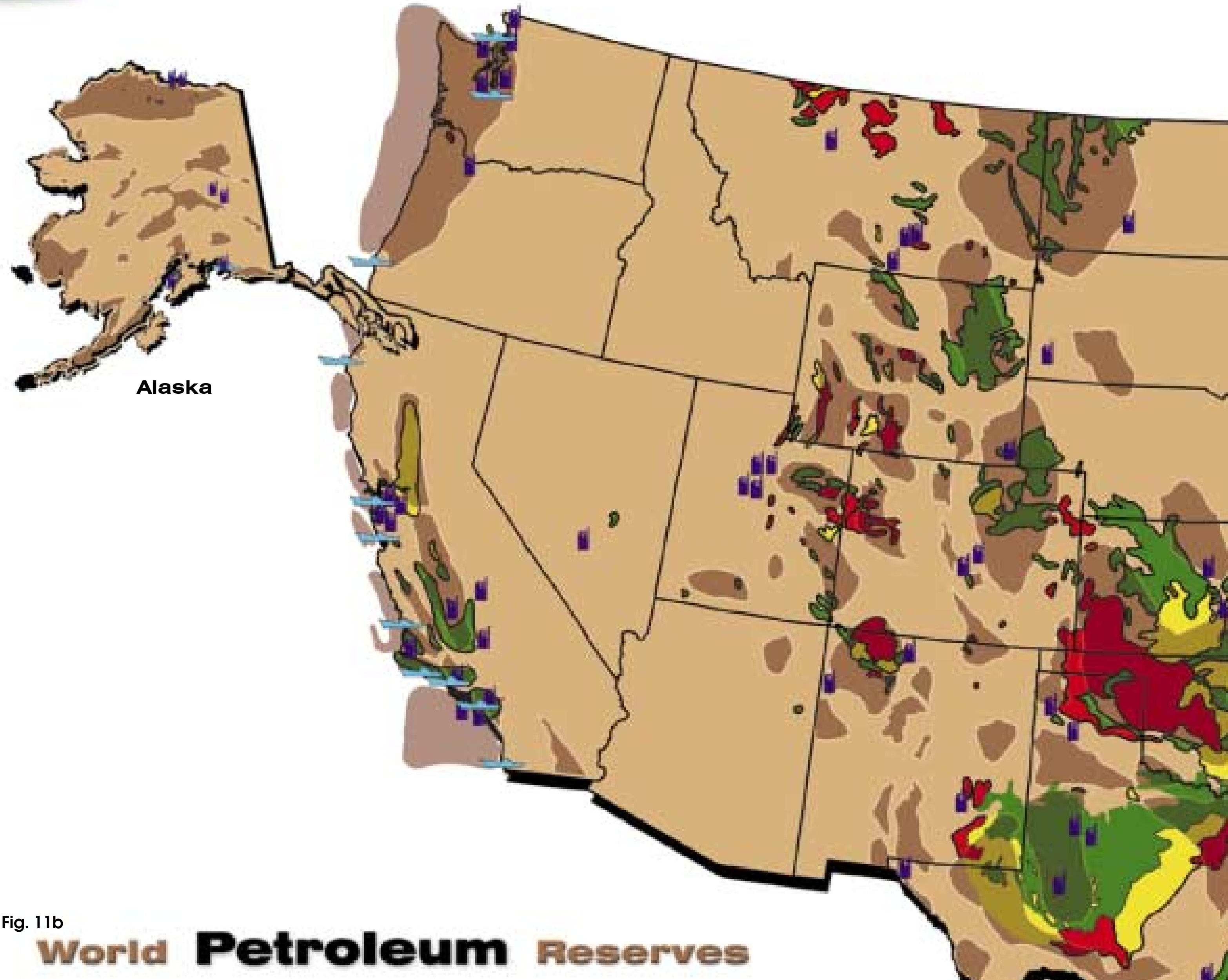



Fig. 11b

## World Petroleum Reserves

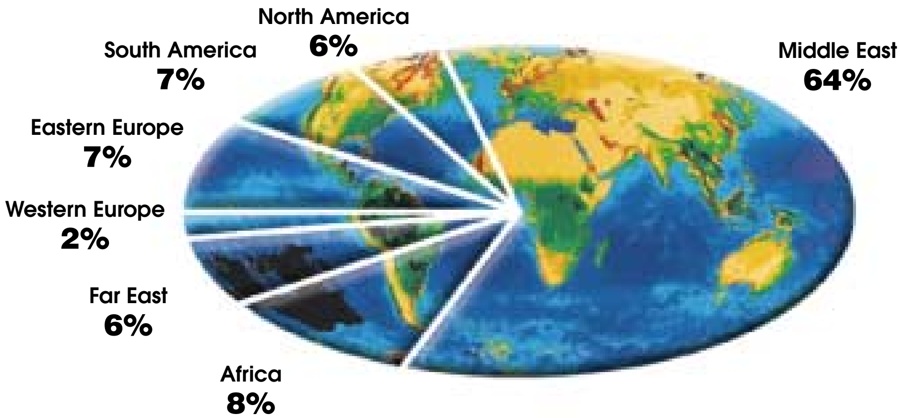



*Fig.11 b. The world's petroleum reserves are far from being uniformly distributed. The United States, Canada, and Mexico together contain less than six percent of the world's estimated petroleum reserves.*

Fig. 11a

# Petroleum Production

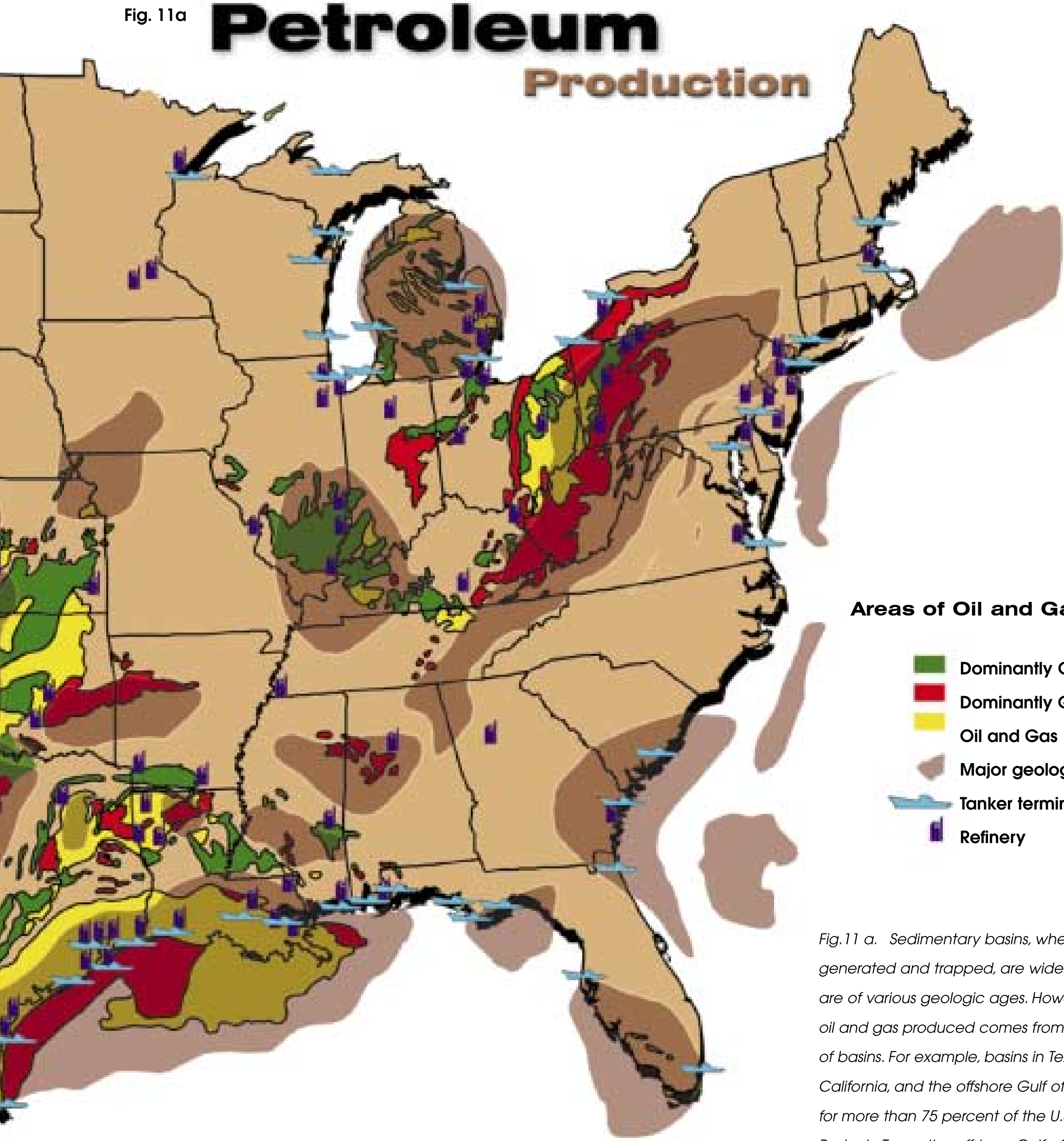



*Fig.11 a. Sedimentary basins, where petroleum is generated and trapped, are widely distributed and are of various geologic ages. However, most of the oil and gas produced comes from a small number of basins. For example, basins in Texas, Alaska, California, and the offshore Gulf of Mexico account for more than 75 percent of the U.S. oil produced. Basins in Texas, the offshore Gulf of Mexico, New Mexico, Wyoming, and Oklahoma account for about 65 percent of the natural gas produced in the United States.*

# FINDING AND PRODUCING PETROLEUM 2

Although technological advances have greatly improved the odds for success, the only way to determine conclusively where petroleum occurs is to drill an exploration well. Geoscientists combine advanced technologies and their knowledge of the Earth processes that control petroleum distribution. They seek evidence, look for patterns, analyze data, and develop hypotheses as to where oil and gas may be found. Petroleum exploration ventures are exciting, but they are also extremely costly and carry a high degree of uncertainty.

## Geoscientists at Work

Petroleum exploration draws on the expertise of a variety of earth scientists including geologists, geophysicists, and paleontologists. The scientists search for clues regarding petroleum source rocks, reservoir rocks, and traps. They combine data obtained from previous wells (even non-productive wells called dry holes), rock samples collected from wells, and surface exposures of rocks to predict the subsurface distribution of petroleum and determine the best location for drilling. Their ultimate target is a subsurface trap where reservoir rock is likely to contain petroleum.

Geophysicists use sound waves that move through rocks and are reflected back to the surface from boundaries between layers of rock to identify subsurface areas where petroleum traps may exist. The most common technique is a very powerful exploration tool called **reflection seismology** (Fig. 12). Historically, transmitting sound waves into the ground involved detonating small amounts of dynamite in a series of shallow, small-diameter holes. Today, machines that generate sound waves by vibrating very heavy weights against the ground have largely replaced explosives. The waves are reflected back to the surface where a device called a geophone records their time of arrival. By knowing when the vibrations are generated and recorded, the velocity with which the sound waves move, and the time when the reflected sound wave returns to the surface, it is possible to estimate the depth and distribution of specific rock layers underground. In the oceans, sound waves are produced by the sudden release of compressed air in the water column, and the hydrophones are towed in an array behind the survey vessel (Fig. 13). In both onshore and offshore areas, seismic surveys provide information on the geometry of subsurface rock layers as well as the physical properties of the rocks and fluids underground. These data are used to make maps that show subsurface geologic conditions and help identify areas most likely to contain petroleum.

Fig. 12
## Reflection Seismology

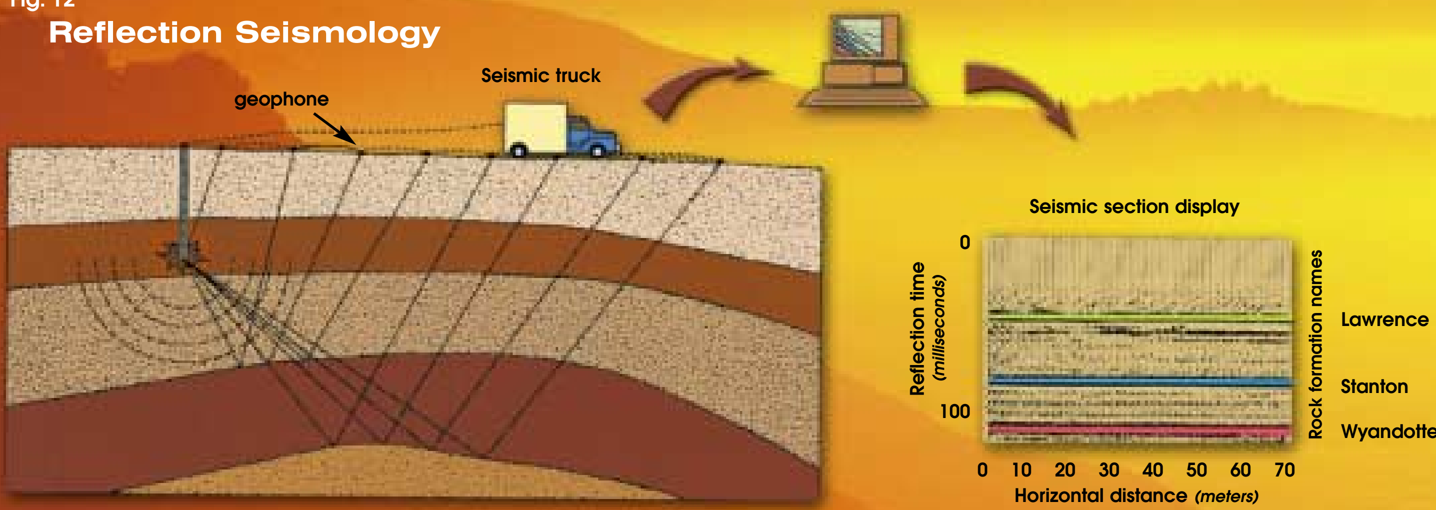



*Fig 12. Sound waves from an energy source are reflected upwards when a change in rock properties is encountered. The major components of a seismic system include a source of energy, sensors (geophones) laid on the ground to record sound waves, and a computer to process signals.*

Fig. 13
## Marine Seismic Survey

*Fig. 13. Modern seismic vessels like this one collect data from the world's offshore regions.*

*Early offshore seismic surveys conducted in the 1950s generated sound waves with explosives that could disturb fish and wildlife in the general area. Less-disruptive acoustical devices are now used.* These new devices substantially reduce the noise that may disturb humans and wildlife. Advanced seismic detectors, powered by batteries, send seismic data via radio signals and can be deployed unobtrusively in sensitive onshore environmental settings. This "wireless" technology eliminates the need for seismic recording trucks or related vehicles to be directly connected to the geophone arrays. Seismic operations are also planned to avoid disturbances in specific places and times such as those where birds nest, caribou birth, and whales migrate.

## Drilling To Test the Trap

After geologists and geophysicists have defined a subsurface trap that may contain economic quantities of petroleum, it is necessary to drill a well. Exploration drilling rigs come in a variety of shapes, sizes, and designs. Small drill rigs with limited depth capacities, which can be mounted on trucks and are easily moved, can often drill wells in just a few days. The largest onshore rigs are more than 200-feet tall. They may

**on-shore**

occupy several acres of land for drill pipe storage, required drilling equipment, and crew quarters. Such rigs require many trucks to transport the large components to the drill site (Fig. 14). These large rigs are capable of drilling wells to depths of 25,000 feet or greater; wells this deep may take many months to complete. Remote locations in environmentally sensitive areas that do not have roads can be explored by using drilling rigs that are transported by airplane or helicopter (Fig. 15). Offshore drilling rigs are large floating structures that can be towed to drill sites, and some of the new rigs can drill in water depths of more than two miles. Supply vessels operating out of the nearest seaport support the needs of offshore drilling rigs.

**off-shore**

*Fig. 14. Although rarely needed, large on-shore rigs can drill 5 miles or more into the Earth in search of oil and gas. Using modern marine drilling equipment, the deep-water production record was set in offshore Brazil at just over 6,000 feet.*

*Fig. 15. This drill rig in Papua New Guinea was lifted into place in sections by helicopter, thus minimizing the need for extensive jungle clearing and road building. The four-wheel trucks shown here came up narrow mountain roads that could not be used by larger vehicles.*

A recent development in both onshore and offshore drilling technology is **directional drilling**. This technique uses boreholes that can be drilled at various angles and become horizontal as they extend downward and away from the drill rig (Fig. 16). With this technique, traps can be tested that are several miles laterally from a drill site, allowing a drill rig to be placed where it will have the least environmental impact. Because horizontal drilling exposes more reservoir rock to the bore hole than vertical drilling, the technology can also be used to produce oil more efficiently from traps that cannot be developed economically by using traditional vertical wells, while decreasing the "footprint" of the production facilities (Fig. 17).

*Fig. 16. Directional drilling technology allows exploration drilling to occur in areas with limited access. Thus prospects that are 3-4 miles from the rig can be evalutated. This technology also allows many development wells to be drilled from a small surface area.*

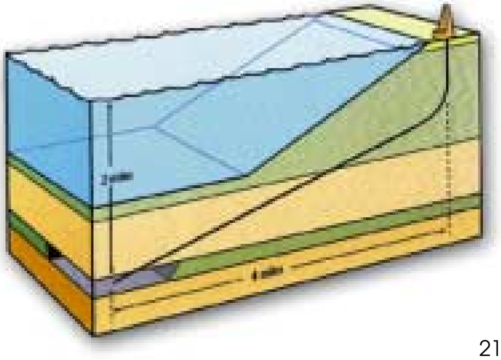


Fig. 17

# Alpine Oil Field Alaska


The large low-pressure tires on rolligons prevent damage to the permafrost. Alpine is the first production facility on the North Slope to depend entirely on temporary ice roads to provide access. As summer approaches, the ice roads melt away leaving the tundra undisturbed. Only aircraft service the Alpine production facility during the summer.


Overview of Alpine facility.

The Alpine oil field is in the delta of the Colville River on the North Slope of Alaska, less than 10 miles south of the Arctic Ocean. This is a treeless region of tundra, permafrost, many scattered ponds and lakes, and several channels of the Colville River. The area contains abundant wildlife, much of it important to the local Inuit village, including caribou, fish, polar bears that den along the coast, and many species of migratory birds that spend their summer here.

Alpine was discovered in 1994 and began production in late 2000. It contains over 400 million barrels of economically recoverable, high-quality oil and is 34 miles west of the nearest oil field facilities at the Kuparuk oil field. The technology used to develop Alpine contrasts sharply with that at Kuparuk even though production at Kuparuk began in 1981, only 19 years earlier. The key differences that characterize recent Alpine exploration and development include roadless access, new drilling technology, and innovative pipeline construction. These advances combine to make Alpine more environmentally sound as well as more economically viable.

Permanent gravel roads to Alpine have not been needed because ice roads, constructed by transporting water from nearby lakes and letting it freeze on the tundra where a road is needed, provide access for large equipment. Ice roads are not used after about April of each year. They are allowed to melt away as summer approaches leaving the underlying tundra undisturbed. Although ice roads have been used for many years to facilitate environmentally sound exploration activities such as remote drilling, Alpine is the first production facility on the North Slope to depend on them. Only aircraft service the Alpine production facility during the summer.

Advances in drilling technology have been especially important at Alpine. Here wellheads can be placed only 10 feet apart on the production pad, whereas at Kuparuk they were originally 120 feet apart (new wells at Kuparuk are now only 15 feet apart). Fewer wells and drill sites are also needed at Alpine because horizontal well bores are used to develop the field, whereas only deviated wells were possible at Kuparuk. Alpine wells are deviated until they reach the reservoir interval and then

*Close wellhead spacing and horizontal drilling technology resulted in only two drill sites to develop the entire 22 square mile area of Alpine.*

they are turned and drilled horizontally through it; the well bore can extend up to a mile within the oil-bearing reservoir, even in places where the reservoir is only 20 to 60 feet thick! At Kuparuk, even highly deviated wells encounter only about a hundred feet or less of the reservoir interval. Close well-head spacing and horizontal drilling technology mean that only two drill sites are needed to develop the entire 22 square mile area of Alpine. As a result, the total gravel-covered area at Alpine, its footprint, is only 97 acres or about half that used at Kuparuk for the same size of developed field area.

Key technical advances in pipeline construction were also employed at Alpine. The pipelines needed to transport oil from Alpine back to the Kuparuk facilities (and eventually to the Trans Alaska Pipeline) were placed 100 feet below the Colville River. Crossing the Colville River by boring holes and placing the pipelines deeply underground and below environmental concerns at the river crossing was a first for North Slope oil field development. As a result, a bridge over this large and annually frozen river was not needed. As there are many rivers on Alaska's North Slope, technology that enables oil and gas to be transported without building bridges is an important advance. The vertical expansion loops in the Alpine pipeline reduced the number of support pilings that were needed, created caribou crossing areas, and replaced shutdown valves — the biggest cause of leaks in old pipelines.

*The pipelines needed to transport oil from Alpine were placed 100 feet below the Colville River eliminating the need for a bridge.*

*Protecting shallow freshwater aquifers from possible petroleum infiltration is a very important step in drilling and completing oil and gas wells.* Modern techniques that protect aquifers were not routinely applied in the early days of exploration and production. As a result, some areas have inherited environmental problems from old wells that were not drilled or abandoned in accordance with current practice (Fig. 18). Today, freshwater-bearing rock layers, **aquifers**, in the uppermost portions of a borehole are isolated from contact with drilling fluids by cementing a large steel pipe, the surface casing, between them and the well bore.

Modern rigs drill through rock materials with rotating bits made of very hard metal alloys, some impregnated with diamonds, that can cut through the hardest of rock formations. The drill bit cuts the rock formations into small chips called **cuttings**. The cuttings are brought to the surface by circulating **drilling mud** through the drill pipe down to the bottom of the hole and then back up through the space between the drill pipe and the rock. Drilling mud, a mixture of water, clays, and chemical additives, is a heavy viscous fluid. As the mud carries the cuttings to the surface, it simultaneously cools and lubricates the cutting surfaces on the drill bit. At the surface, the cuttings are separated from the drilling mud, which is then circulated back into the drill hole. Cuttings provide important information about the kinds of rock formations that are being drilled. From cuttings, geologists identify the rock formation, determine if the penetrated rock layers contain oil, and evaluate them for the properties needed to hold petroleum. These visual evaluations are made as the well is being drilled.

When drilling is stopped, geophysical instruments are lowered into the well bore. This step, called **logging**, provides electrical and physical measurements of both rocks and the fluids they contain. Logging provides details about the types of rocks penetrated by the well, whether porous and permeable rocks are present, and the kind of fluids (oil, natural gas, or brine) they contain. These results constitute the first information obtained to determine whether a well will be productive or a "dry hole."

*Cuttings and excess drilling mud are waste products of the drilling of all petroleum wells and must be safely disposed.* Historically, drilling mud and cuttings were placed in nearby surface pits and allowed to dry before covering them with soil.

before

after

*Fig. 18. This improperly abandoned well in northeastern Oklahoma* ***(before)*** *has been remediated* ***(after)*** *and the area returned to its original state as pasture.*

before

after

*Fig. 19.* ***(before)*** *The photo of this fairly large mud pit in west Texas was taken soon after the pump was installed.* ***(after)*** *Approximately the same location four years later after the site had been back-filled and seeded with fourwing salt bush, a plant which obviously grows well here.*

Many old pits that were environmental problems have been reclaimed and the land returned to a useful condition (Fig. 19). Today, appropriate disposal of drilling mud and cuttings is required and is an important part of all environmentally sound drilling programs. The Environmental Protection Agency (EPA) classifies most drilling mud as non-hazardous, and it can be reused in other drilling operations after it has been cleaned of cuttings. Although cuttings are sometimes reused for construction purposes, such as the development of levees or making bricks, they are typically disposed of by one of the following methods.

- A relatively new disposal technique is the grinding and injection of mud and cuttings back into deep subsurface rock formations. This method is used in sensitive environments like the Arctic to avoid surface disturbance.
- If tested and found safe, and with the permission of the landowner, drilling mud and cuttings can be disposed of on-location. The wastes, which are normally spread, tilled and revegetated, may enrich the soil with fresh minerals. Drilling mud and cuttings are also disposed of in landfills designed for exploration and production wastes.

Surface pits, which were previously dug on-site and used to mix muds and hold them for use in the drilling process, are being replaced by portable storage tanks. Using tanks avoids surface disturbance and allows better mixing of mud and mud additives.

*Another significant environmental concern associated with exploration drilling is the possibility that the bore hole will encounter unexpected high pressure conditions in a rock layer that result in uncontrolled escape of petroleum to the surface — a blowout.* In the early days of the petroleum industry, blowouts were the subject of some spectacular historical photographs (Fig. 20). Thanks to technology, the classic image of a spouting oil well and its economic and environmental consequences are largely a thing of the past. Today, a series of down-hole and surface sensors continuously monitor mud-weight and pressure conditions

as wells are being drilled. This computer-controlled monitoring allows immediate adjustments to the drilling mud system if down hole pressure conditions change quickly. If an unexpected high-pressure zone is encountered during drilling, and if the flow cannot be controlled by drilling mud adjustments, a set of redundant valves on the drill rig, called "blowout preventers," are activated. These valves mechanically close the well to prevent the escape of well bore fluids. Even with these precautions and controls, blowouts can still occur.
If a blowout occurs, a second well can be drilled to intersect the well bore of the uncontrolled well. Heavy drilling mud is then pumped into the uncontrolled well to stop the blowout. Blowouts have become increasingly rare as a result of the wide-spread use of technological advances and standard procedures to avoid such accidents.

## Producing Petroleum from a Well

While drilling for petroleum, boreholes commonly penetrate water-bearing formations. Unless special steps are taken, large quantities of this saline **formation water** can enter the oil well.
To minimize water production, a barrier is placed between the petroleum bearing rocks and water-bearing formations by installing a pipe of smaller diameter than the casing inside the well bore. Cement is pumped through the bottom of the casing to fill the space between the casing and the rock formations it passes through. This barrier of cement effectively seals off rock formations and prevents the fluids they contain — oil, water, and natural gas — from entering the casing. The next challenge is to perforate both the steel casing wall and the cement barrier in such a way that petroleum fluids — but little or no formation water — will move from the reservoir rock into the casing. To accomplish this task, explosive charges — which look like large bullets — are lowered down the hole on a cable to the exact depth of the petroleum-bearing rocks. The precise depth is known from measurements collected during the geophysical logging. When the charges are fired, the bullets shoot through the adjacent casing and the cement creating openings to only the petroleum-bearing formation. Using a casing and cement

*Fig. 20. Spectacular blowouts were much more common decades ago, such as this fire at Spindletop oil field in Texas in 1902. Today, blowouts are most likely to occur when the first wells are drilled into deep and poorly known rock formations. This blowout and fire occurred in 1988 in the Cook Inlet area of Alaska.*

*Fig. 21. Flares such as the one shown at this offshore platform have historically been a source of emissions to the atmosphere. The practice has largely been halted in the United States by regulations and is primarily allowed only under emergency orders.*

barrier to separate the petroleum bearing rocks from water-bearing layers reduces the amount of formation water that can enter a well and allows petroleum — oil, gas, or both — to flow into the casing and to the surface through the production tubing.

Many petroleum-bearing reservoirs contain some water mixed with the oil and gas. As production continues, it is common for the amount of oil and gas a well produces to decrease and the amount of water to increase. Because the majority of petroleum wells in the United States have been in production for a long time, their production now averages about 6 barrels of water for each barrel of oil taken from the ground. It is necessary to separate the gas, oil, and water. Natural gas is the first thing removed from the mixture and it goes into a separate gas line. Historically, if the amount of gas produced did not warrant separation, it was injected into the reservoir or burned (flared) near the wellhead (Fig. 21). The practice of flaring gas, which was formerly a source of carbon dioxide emissions to the atmosphere, is typically allowed in the United States only under emergency orders from the appropriate regulatory agency.

The fluid mixture goes through a heating unit where gas, oil, and water are separated. The separated oil is moved into storage tanks and transported to a refinery by truck, pipeline, or ship. Formation water from deep within the Earth is commonly too rich in dissolved salts to be discharged directly onto the surface or used for other purposes, such as irrigation, without treatment. Thus, the remaining produced water is a normal but undesirable by-product of petroleum production.

*Produced water is the most common oil field waste and it must be disposed of safely.* Where produced water is fresh enough, it can be treated and used for agricultural purposes. In some locations, produced water is converted into freshwater by using a freeze-thaw/evaporation process. Formation brines are mostly disposed of by re-injecting them into deep subsurface porous zones, or they are used in water flooding, a technique that increases petroleum production by injecting produced water back into petroleum reservoirs and recovering additional oil. A new technology known as downhole water separation can minimize produced water by separating the water within the well and re-injecting it into rock formations. Because this process allows only oil to come to the surface, it will greatly reduce produced water handling and disposal problems in the future.

Until the 1950s, production facilities commonly discharged produced water onto the surface, where it harmed vegetation and contaminated soil and water. Depending on local conditions, these sites could take decades to fully recover on their own. Since then techniques have been developed and used to reclaim these old brine-contaminated areas. A common remediation technique for brine-contaminated soil is **land farming**. In this approach, common amendments such as gypsum and organic fertilizers are tilled into soils affected by produced brines. The area is revegetated, initially with salt-tolerant plants, to reduce erosion and help restore soil fertility. With increased permeability, rain or irrigation water leaches salt from the soil over time, restoring soil productivity.

*Fig. 22. Modern oil field production. The island in the foreground with the white tower is an artificial structure that houses a drill rig. This oil field produces 9,000 barrels of oil per day from 200 wells.*

## Developing Production Facilities

Oil and gas fields have been discovered and developed in urban areas (Fig. 22) as well as in very remote and undeveloped regions. Large oil and gas fields may extend over thousands of acres, have miles of pipelines to gather produced fluids, and need facilities to separate petroleum. Early development of productive fields was typically done with many close-spaced wells, and some lasting images of these early fields highlight the physical disturbances that accompanied them (Fig. 23).

*Fig. 23. Early oil field production.*

*Today the petroleum industry takes great measures to minimize the environmental impact of all exploration and production activities.* Reducing the physical disturbances caused by petroleum operations on sensitive ecosystems and in urban and rural communities has been achieved in many ways. Petroleum production operations are now much smaller, quieter, and more compatible with their natural or urban environments.

Advances in drilling technology have led the way. Modular drilling rigs and rigs that use lighter and smaller diameter drill pipe now allow operators to conduct exploration programs with equipment that is up to 75 percent smaller and lighter than conventional rigs. These advances reduce drilling impact and the area needed for drill sites. Helicopter-transportable rigs allow remote and environmentally sensitive sites to be accessed without the need to construct roads (Fig. 15, p. 21). In the Arctic, exploration is done in the winter so that ice roads and pads can be used for operations. Such temporary facilities simply thaw and melt away in the summer and leave the tundra undisturbed (Fig. 24)

Drilling rigs are also more efficient. Improved drill bits and new capabilities, such as down-hole sensors which allow real-time monitoring of drilling conditions, enable well bores to be drilled twice as fast as 10 years ago. Mufflers are installed on many types of equipment to reduce the noise of oil and gas operations, and electrical motors can be used if further noise reduction is needed. Protective covers, or "bonnets," can be installed to protect birds from flying into vents on drill rigs.

By using newer techniques such as horizontal drilling, hydraulic fracturing, multilateral and dual completions, the number of wells needed to recover oil and natural gas have been significantly reduced. The extended-reach, or horizontal, wells (Fig.16, p. 21) can access oil and gas reserves miles away from the surface location and recover oil and natural gas lying under sensitive environments. Extended-reach wells combined with new wellhead production techniques significantly reduce the area needed for petroleum production (Fig. 25). New electronic monitoring capabilities combined with remote telemetry enable


*Fig. 24. On the North Slope of Alaska, drilling is done during the winter. Equipment is removed on ice roads while the tundra is still snow covered. During the spring and summer, the wellhead box is all that remains.*

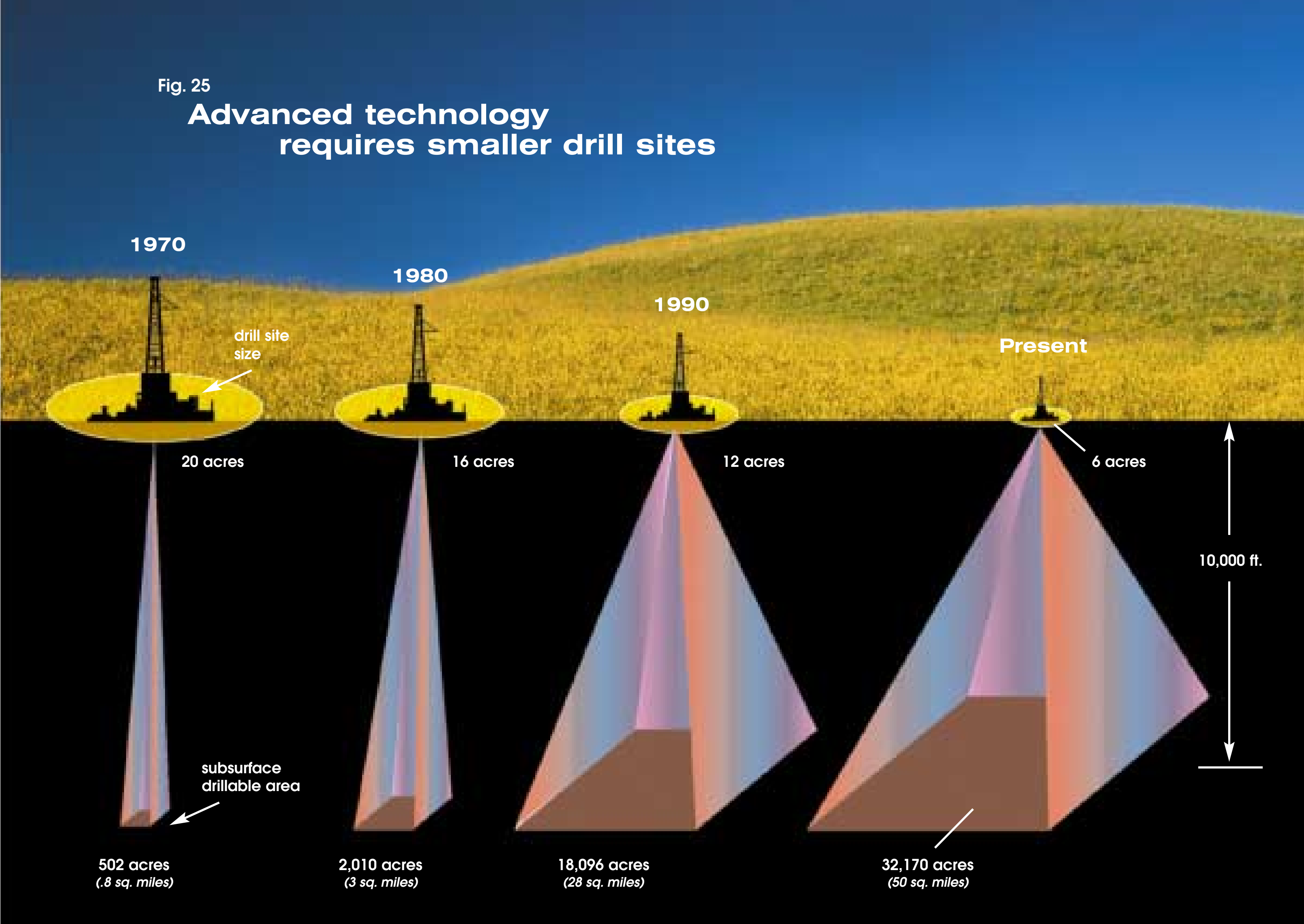



*Fig. 25. Major improvements in drilling technology over the last 30 years have resulted in much smaller drill sites.*

production operations to be conducted without onsite workers. Because workers only visit the location for routine maintenance or repairs, some of these facilities have been developed without road access.

Current operational practices also use camouflage to make facilities less obtrusive. In some areas, production facilities are hidden by vegetation so they cannot be easily seen. In metropolitan environments, drilling rigs have been disguised in order to blend in with the surroundings, and production facilities cannot be distinguished from urban structures (Fig. 26).

*Fig. 26. A disguised urban oil field adjacent to a California marina. The tall white structure on the island conceals a drilling rig.*

# MAKING FUELS AND PETROLEUM PRODUCTS

3

Almost all petroleum goes through some type of processing before it can be used. For example, crude oil must be refined to separate the complex mixture of hydrocarbons into various compounds. In addition, natural gas may contain undesirable levels of non-hydrocarbon components that must be removed, such as sulfur compounds that smell like rotten eggs. In the early history of the petroleum industry, refineries were located close to areas where oil was produced, but as pipeline technology improved, it was possible to move crude oil over greater distances. The United States has more than 160 refineries (Fig. 11, p. 16) with a total daily processing capacity in excess of 19 million barrels; many refineries are now located in coastal areas in order to accommodate imported oil delivered by marine tanker vessels.

In order to understand the environmental concerns associated with refining of petroleum, it is important to understand what happens at a refinery. Refineries are large, complex facilities that use a variety of chemical and physical processes to separate, convert, purify, and blend a broad range of petroleum products. These processes have become highly efficient and virtually all the oil and natural gas that goes into a refinery is used in one form or another. Refineries produce the following products:

- Transportation fuels such as gasoline, diesel, and jet fuel;
- Chemical feedstocks used to make plastics, fertilizer, and medicine;
- Lubricating oils, greases, and waxes; and
- Residual components such as bitumen, asphalt, petroleum coke for furnace fuels, and sulfur.

## Separating Petroleum Components

One of the first steps in converting crude oil to useful products involves a separation process called **distillation.** This process requires that a liquid be heated to its boiling point and the produced vapor cooled so that it condenses back to a highly purified liquid form. The distilling of water is a well-known example; water is heated to its boiling point, 212°F, so that it vaporizes, the vapor is cooled, and the resulting condensed water is extremely pure. Distillation of crude oil is more complicated because it is a mixture of hydrocarbons, each of which has its own boiling-point temperature. For example, a certain type of hydrocarbon compound that has eight carbon atoms per molecule, an octane, will boil at a temperature of about 259°F, one with 10 carbon atoms (decane) will boil at 345° F, and one with 12 carbon atoms (dodecane)

**Fig. 27**

## Crude Oil Distillation

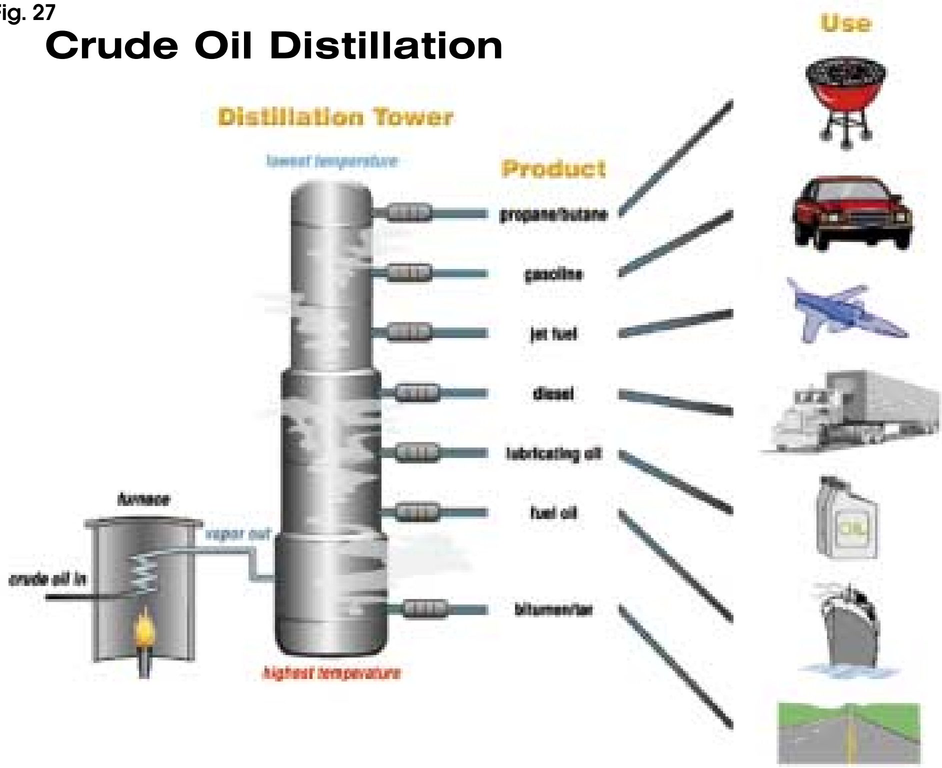



*Fig 27. Distillation is a key process in refineries and allows a complex mixture of hydrocarbons to be separated into many types of consumer products.*

**Fig. 28**

## Workers' Injury Incident Rates at Refineries vs. U.S. Manufacturing


*Fig. 28. The frequency of injury rates at refineries is lower than the average of all U.S. manufacturing facilities.*

will boil at 421°F. In refineries, distillation starts with vaporized crude oil being placed in a tall tower that is cooler at the top than it is at the bottom. The different hydrocarbon compounds separate at various temperatures, and the liquids are selectively withdrawn from the tower. By drawing off hydrocarbon liquids that have similar boiling points, a range of products is collected. Among them are liquified petroleum gases (such as the propane used in outdoor grills), gasoline, kerosene (and its close cousin, jet fuel), diesel fuel, lubricating oil, fuel oil, and tar (Fig. 27).

*The principal concerns associated with distillation at refineries are safety-related.* Because hydrocarbons are highly flammable, it is critically important to protect against accidental fire and explosions in refinery processing operations. Inadvertent leaks, such as the failure of a key valve, can create hazardous conditions. If accidents do occur, workers may be injured or killed, and toxic fumes may be released into the atmosphere. Over the last few decades, however, comprehensive safety laws and regulations have been put into place and are strictly enforced by local, state, and federal agencies. The high safety standards at modern refineries appear to be effective, as refineries have a much lower accident/injury rate than the U.S. manufacturing sector overall (Fig. 28).

## Converting Petroleum Components

Conversion changes the chemical composition of the various components separated by distillation and allows them to become both end products and building blocks for other products. Conversion processes include breaking large molecules into smaller ones — a process generally known as '**cracking**'— and converting or combining various hydrocarbon components into different molecules. There are several ways to crack molecules. Thermal cracking is carried out by extreme heating, and large hydrocarbon molecules are broken into progressively smaller ones. The use of **catalysts**, materials that increase the speed of chemical reactions, to assist cracking is the most commonly used conversion process in the United States. The process is called 'cat-cracking' and it produces about 40 percent of all domestically refined gasoline. Many other conversion techniques depend on heat, pressure, and catalysts, but they all aim to change products of distillation into other more valuable compounds.

*The escape of gases into the atmosphere is a principal environmental concern at all petroleum facilities, but especially during conversion and other processing.* The major sources of emissions into the atmosphere from petroleum facilities such as refineries are

- Flue gas from process furnaces and steam boilers;
- Fugitive emissions, which are low levels of volatile hydrocarbons that escape from storage tanks, valves, and processing units;
- Gases from burning waste hydrocarbon compounds. These burning gases are the flares seen at refineries, petrochemical plants, and at some production sites; and
- Exhaust fumes from engines used to run everything from compressors to on-site electrical generators.

Technological innovations and process changes are helping to reduce emissions at oil and natural gas facilities and refineries:

- Refineries and electric utility companies have traditionally generated steam and electricity separately, with both processes having energy losses. By using a gas turbine to generate electricity, and the exhaust from that turbine to generate steam (a process known as co-generation), overall efficiency can be improved by as much as 40 percent.
- Modern refineries typically have computer-controlled process and energy control systems that reduce energy consumption.
- More energy-efficient engines with catalytic converters and improved furnace and boiler burners have been installed.
- Infrared emissions monitors have been developed, which help operators identify the source of difficult-to-locate fugitive emissions.
- Control valves, once a major source of fugitive emissions throughout refineries, have been greatly improved.

Fig. 29

**U.S. Refinery Emissions Reductions**

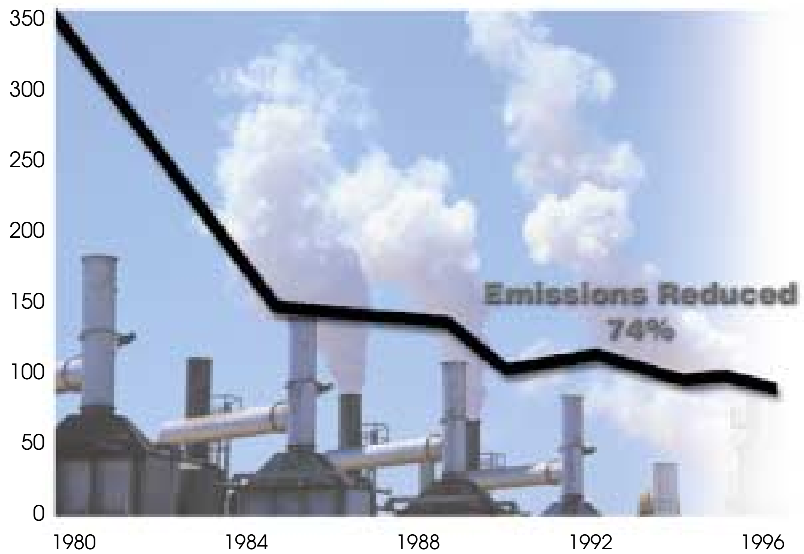



*Fig. 29. U.S. Refinery Total Criteria Pollutant Emissions (10,000 short tons per year). Since 1980, new technologies and improved processing have reduced harmful emissions at petroleum facilities and refineries by nearly 74 percent.*

- Flaring is being reduced and the emissions that were previously burned now serve as fuel for process furnaces and boilers.
- Vapor recovery units have been installed on storage tanks to reduce the loss of volatile hydrocarbons to the atmosphere.

As a result of these and other improvements at petroleum facilities, criteria pollutant emissions have declined 74 percent since 1980 according to U. S. Environmental Protection Agency data (Fig.29). Criteria pollutant emissions, such as particulate matter, sulfur oxides, and ozone produced from nitrous oxides and volatile organic compounds, are major contributors to smog and acid rain.

## Removing Impurities

Refinery products are treated to remove components that affect critical processes or result in poor-quality products. However, the resulting refined product may still be undesirable because of the presence of sulfur and nitrogen in some crude oils. For example, when sulfur and nitrogen compounds are present in combustible fuels in sufficient quantities, unacceptable levels of sulfur dioxide and nitrous oxides are discharged as exhaust emissions. These can degrade air quality. Treatment techniques have been developed to remove sulfur and other materials. Nitrogen is commonly isolated from a process stream and recovered, primarily for use in the manufacture of fertilizers. Another treatment technique removes unwanted metals, which can be concentrated and stockpiled until they are sold.

*Responsible management of wastes at refineries focuses on reuse or appropriate disposal.* Refinery wastes are by-products of the refining process. Typical wastes include the caustic materials used to remove impurities, biomass derived from micro-organisms used to treat refinery waste water, spent catalysts, and emulsions (a mixture of oil and water that remains after oil/water separation occurs). Approximately 3 million tons of waste — about half ton of waste per 1000 barrels of crude oil refined — are generated each year in the United States.

Refiners rely on recycling and treatment to reduce the amount of waste that will require disposal:

- Catalysts are routinely recycled and reused again and again.
- Most of the spent caustics are treated to make them inert.
- Emulsions are collected and used in the refining process.
- Water is removed from biomass to reduce its volume, and biomass is recycled; some biomass may be blended with crude oil and used in the refining process.

As a result of these efforts, refiners recycle 60 percent of the waste materials and treat over 20 percent of them to make them inert. Less than 20 percent of total refinery wastes now require disposal, and those wastes are most commonly placed in specially designed protective landfills.

Storage tank wastes can develop wherever petroleum is stored, especially in the large "tank farms" that characterize refineries. Thick sludge that settles to the bottom of storage tanks (tank bottoms) is a mixture of tarry components and solids composed primarily of sediments that are produced with oil. These materials need to be removed periodically when tanks are cleaned and inspected. To reduce disposal volumes, tank bottoms today are routinely recycled. They are either used to make asphalt or combined with crude oil and used as a feedstock in the refinery process. The petroleum components of tank bottoms can also be removed using bioremediation, and the oil free sediment mixture can then be spread on site or disposed of safely.

*Because so much petroleum passes through refineries each day, preventing spills that could contaminate soil or groundwater is a major environmental concern.* Protecting against such spills is among the most important operating guidelines at all refineries. Spills have been more common at older refineries where corrosion and equipment failures cause leaks. As a result, many old refineries have been the sites of major soil and groundwater remediation projects.

Where leaks and spills have occurred, actions are taken to restore sites so that they do not pose a threat to human health or the environment. A number of technologies and approaches have been developed to restore sites where soil, groundwater, or surface waters have been adversely affected by petroleum or petroleum products. Although these technologies can be effective, they can also be slow processes that may take anywhere from a few years to many years to restore petroleum-affected sites adequately.

## Restoring Soils

If soils become contaminated with petroleum, they can be remediated in several ways. The optimum method for a given area will depend on site-specific factors, such as the soil type and the amount and type of contamination. However, common remediation methods include excavation and disposal, land farming, bioremediation, vapor extraction, stabilization, or soil reuse.

Excavation and disposal involves physical removal of contaminated soil using conventional excavation techniques and disposal of the contaminated materials in appropriate landfills. This approach relocates contaminated soils to a better long-term disposal facility, but it can be expensive and does not reduce the amount or change the character of the contaminated material.

■ Bioremediation is a highly effective technique that relies on naturally occurring microorganisms that use hydrocarbons as food. The microorganisms convert petroleum into non-toxic microbial biomass, carbon dioxide, and water. Bioremediation is a natural process that is always at work in the environment. Remediation applications commonly involve supplying additional air, water, nutrients, and microorganisms to speed up the process.

Vapor-extraction technology can be used to remove semi-volatile and volatile organic compounds, such as gasoline, from soils. The removal is accomplished by drilling wells into the soil and using pumps to withdraw petroleum vapors. Eventually all volatile compounds are vaporized, captured, burned, or, in some cases, reused.

Stabilization technologies use processes that encapsulate the contaminated soil in a solid that is chemically or physically inert. By decreasing the mobility and bioavailability of contaminants, the stabilized soil can be left in place. Surface caps, such as concrete slabs and compacted clay-rich soil, cover the stabilized material to prevent possible release of contaminants into the atmosphere and reduce surface-water infiltration that may contribute to groundwater contamination.

■ Soil reuse. The incorporation of petroleum-contaminated soil as an ingredient in the production of asphalt is an example of reuse and recycling (Fig. 30). Petroleum-contaminated soil has also been reused in the production of cement and bricks.


*Fig. 30. Oil-contaminated soil can be used to improve roads. In (a), oil-contaminated soil is being blended with asphalt; and (b) shows the blended material being used for paving a road.*

## Remediating Groundwater

Many specialized techniques have been developed to remediate groundwater affected by petroleum. However, contaminated water can be very difficult to remediate, because even low concentrations of some petroleum components make water unfit for many purposes. Petroleum compounds can be dissolved in groundwater, or they can accumulate as a separate liquid phase (such as crude oil, gasoline, diesel, or kerosene) that forms an underground accumulation concentrated on the water table. This accumulation of contaminants that 'floats' on groundwater is called a free-phase hydrocarbon plume.

Like remediation of petroleum-contaminated soil, site-specific factors determine which methods will be most effective for remediating contaminated groundwater in a given situation. Factors to be considered include the local geology and the type and quantity of contaminants present in the subsurface. Groundwater remediation technologies include pump and treat, vapor extraction, bioremediation, in place reactive barriers, and containment.

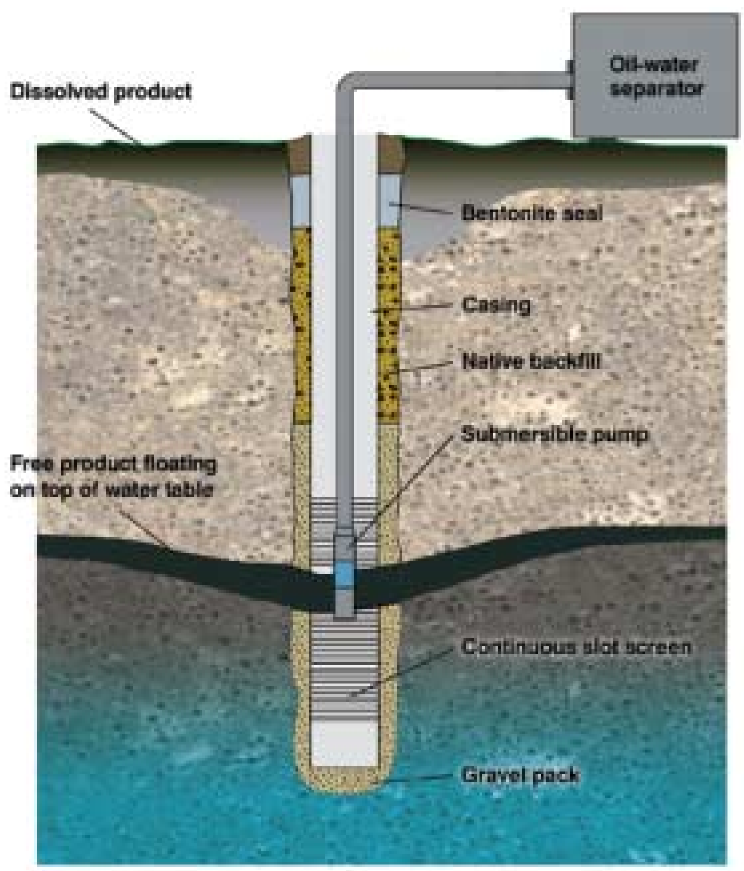
■ Pump and treat techniques use pumps within wells to bring free-phase hydrocarbons, petroleum-contaminated water, or water affected by brines produced with oil or natural gas to the surface for treatment, reuse, or disposal (Fig. 31). If the water table is shallow, surface trenches collect the contaminated fluids. Above ground treatment of the petroleum-affected water uses a variety of methods including carbon absorption, air stripping, oxidation, ultraviolet light degradation, or the use of bioreactors.

- Vapor extraction, a common technique for remediating soils, can also be used to remove volatile free-phase hydrocarbons from below the water table. This technology removes hydrocarbons from the free-phase plume, but it does not remove compounds that are dissolved in the groundwater.
- Bioremediation can also be used to remove petroleum from groundwater and can be effective on both free-phase and dissolved-phase plumes. If the contaminated groundwater does not pose a threat to human health, this natural process is allowed to proceed over time and will eventually remove the contamination. Wells can also be drilled and air, nutrients, or microbes delivered to the plumes to speed up the biodegradation process.
- Reactive barriers can be placed in the ground so that contaminated water flows through them. In this method, a buried wall or series of closely spaced wells are used to form the reactive barrier. Groundwater passing through these barriers is cleaned. If treatment is biological, barriers commonly contain oxygen-releasing compounds that help ensure that microbial populations continue to consume hydrocarbons. Another option involves placing materials, such as activated charcoal, that will adsorb the hydrocarbons from groundwater that flows by.
- Containment is a way to encapsulate petroleum-affected groundwater so that it does not pose a risk to human health or the environment. With containment, impermeable walls are placed completely around the affected groundwater so that it cannot move. This method does not reduce the amount of affected groundwater, and can slow or prevent bioremediation because oxygen and nutrients needed by microbes cannot easily get to them. It is also difficult to ensure that the containment wall is perfect. For these reasons, containment is not commonly used.

*Fig. 31. If petroleum or petroleum products percolate down through soil and reach the water table in large enough quantities, the contaminants literally float, because petroleum and its products are lighter than water. Aquifer remediation is carried out by pumping the free product to the surface for recovery.*

**Fig. 31**

**Treatment of Petroleum-contaminated Water**



# Transporting and Storing Petroleum and Its Products

# 4

Getting crude oil to refineries and products to consumers requires a major petroleum transportation system. The system links road, water, and rail transportation to a national pipeline system and it serves two critical purposes — getting crude oil to refineries and distributing finished products to consumers. This distribution system is as vital to our daily lives as the national electric power grid or the nation's highway system.

## Ocean Transport

Marine tanker vessels carry huge quantities of imported oil to U.S. refineries (Fig. 4, p. 10). Ships especially designed to carry large amounts of petroleum came into widespread use in the 1960s, and they are capable of moving enormous quantities economically. The largest of these ships — huge vessels that can each transport over 4 million barrels of oil per trip — move petroleum at per-barrel costs less than that of pipelines. Because the largest tankers require 85-foot water depths and are bigger than an aircraft carrier, their size restricts where they can take on and discharge crude oil. For example, the Louisiana Offshore Oil Port (LOOP) facility — which had to be located 20 miles off the coast of Louisiana where water depths are adequate — handles between 10 and 15 percent of our imported oil (Fig. 32). As the United States and other countries continue to import large amounts of oil, such facilities and tankers will play an increasingly important role.

*The key environmental challenge associated with ocean transport of petroleum is the prevention of spills.* Accidents and mechanical failures are the primary causes of spills. One of the most widely publicized U.S. spills occurred in Alaska in 1989 (Fig. 33). From an environmental perspective, large spills that may occur in sensitive ecosystems must be prevented if we are to adequately protect the environment.

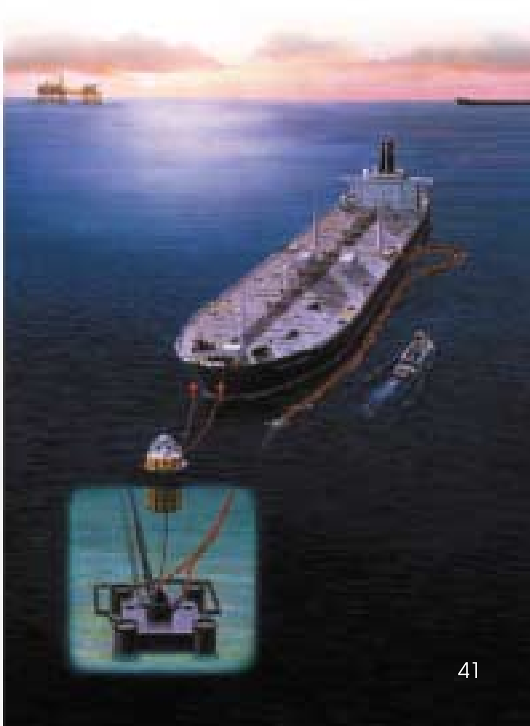
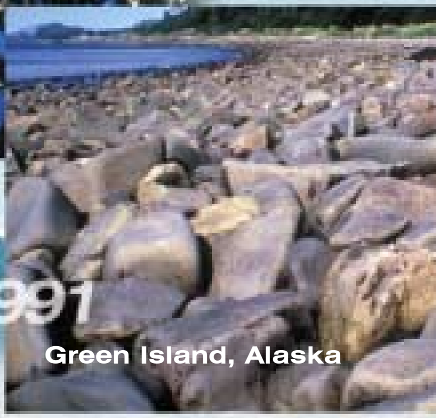


*Fig. 32. Large marine tankers deliver much of the imported petroleum. The LOOP (Louisiana Offshore Oil Port) is one of the few facilities in the world capable of handling the largest vessels afloat.*

Fig. 33

# Lessons *from an* Oil Spill

1989




**In March of 1989,** an oil tanker, the Exxon Valdez, ran aground on Bligh Reef in Prince William Sound, Alaska. The grounding damaged the tanker's hull, releasing approximately 10.9 million gallons of North Slope Alaska crude oil into the ocean. Although this oil spill was relatively small (not even among the top 50 marine spills), Prince William Sound was a pristine setting with sensitive ecosystems and a key area for commercial salmon fishing. The Valdez oil spill changed much about what is now done to prevent such spills, to be better prepared for response, and to select shoreline cleanup methods, as well as to understand the acute and long-term impacts of oil on a wide range of species, communities, and habitats.

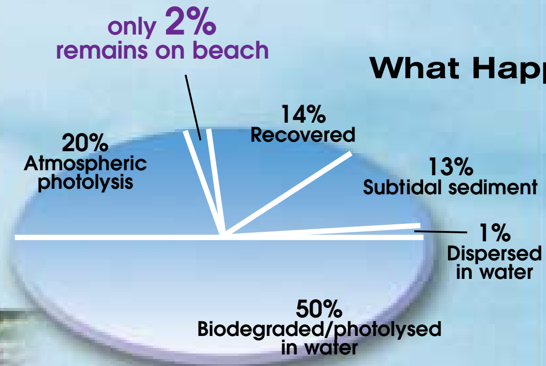
A large number of people and equipment were mobilized to combat the spill. Steam and detergent systems were brought in to clean up beaches. Skimming vessels were used to recover oil floating on the sea and floating barriers were used to control the movement of oil slicks. The extent and degree of shoreline oiling resulted in the most intensive shoreline cleanup effort ever attempted. Despite the aggressive cleanup, oil residues persisted for more than 13 years in more sheltered habitats and porous gravel beaches. Monitoring studies have shown that intensive treatment resulted in delayed recovery of rocky shore intertidal communities. These studies demonstrate how an overly aggressive cleanup, in some instances, can slow recovery of these affected communities.

Salmon harvests in the Sound were relatively high in 1990 and 1991 and then went down to alarming levels in 1992 and 1993. This situation raised speculation that the oil spill may have had a permanent impact on salmon and other fish species in the area. However, the harvest yield of 1994 was one of the highest on record, and harvests in subsequent years have been better than those of 1992-93.

By 1993, many of the beaches that were covered with oil immediately after the spill had largely recovered and very little residual oil was evident anywhere in

http://response.restoration.noaa.gov/spotlight/spotlight.html

## What Happened to the Oil?




*A 1992 NOAA study estimated that the great majority of the oil from the Exxon Valdez either evaporated, dispersed in the water column, or degraded naturally.*

the Sound area. The National Oceanic and Atmospheric Administration reported that green algae, rockweed, and barnacles repopulated many of the affected areas within 2 to 3 years, but some types of clams, limpets, and certain snails would take much longer.

Efforts to ascertain the extent of the environmental impact and the rate of recovery from the Valdez oil spill have been particularly divisive and opposing positions have been hotly debated. Ongoing and future efforts to define the injury and recovery of the ecosystem in and around Prince William Sound due to this oil spill will continue to raise important scientific questions and will contribute greatly to scientific understanding of the effect of releases of petroleum at a variety of scales.

Several improvements in tanker safety and operations have been implemented to prevent spills (Fig.34).

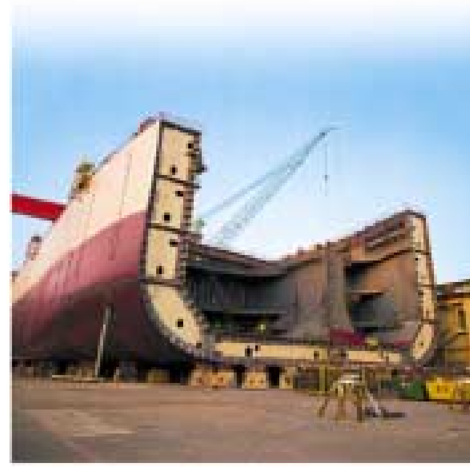


*Fig. 34. The Oil Pollution Act requires that by 2015 tankers operating in U.S. waters have double-hulls. Many double-hull tankers are already in service, and their value in terms of environmental protection has already been demonstrated.*

- Recognition that human error causes many accidents has resulted in operational changes for personnel working aboard tanker vessels. Tanker crews are licensed, and they routinely engage in drills on safe operating procedures. They are subjected to random drug screening tests and, like airline crews, can only work a prescribed number of hours per day to prevent fatigue-related human errors. Virtual reality technology provides extensive hands-on simulator training that helps prepare key personnel for real-world emergency situations at sea.
- Global positioning systems linked to electronic navigation and chart devices allow positive verification of location within 15 feet. The GPS system also sounds an alarm if the vessel is even slightly off course. Tankers are being fitted with AIS (Automatic Identification System), a new capability whereby ships continuously transmit vessel identification, position, speed, course, and related data to nearby ships and to shore stations. Powerful tugboats also now escort tankers through crowded and difficult-to-navigate areas.

**1 barrel = 42 U.S. gallons**

**1 tonne = 294 U.S. gallons**

***gallon = volume measurement***

***tonne = weight measurement in metric tons***

*For truly precise conversions between gallons and tonnes, it is important to take into account that equal volumes of different types of oil differ in their densities and weights.*

■ To help guard against potential spills, legislation passed after the 1989 Alaska spill requires that by 2015 all tankers that travel in the waters of the United States must have double-hulls. This hull-within-a-hull design (Fig. 34, p. 43) greatly reduces chances for an accidental spill caused by collision or grounding. New tanker designs are being developed by computer models and refined by extensive tank testing in order to improve strength, seaworthiness, and maneuverability. Tankers are routinely inspected for metal fatigue and corrosion.

Despite these precautions, spills sometimes occur (Figs. 35, 36, 37). If a spill occurs in inland or coastal waters, efforts are made immediately to contain and recover as much of the oil or product as possible. A nation-wide system of spill response vessels and equipment has been developed that is ready to rapidly deploy if needed. The vessels for this work are custom-built with large holding tanks, mechanical skimming devices, and vacuum systems for recovering oil spilled on water. These vessels can vacuum oil spilled onto surface water as well as remove oil from damaged tankers and barges. They use floating containment booms, composed of adsorbent material, to prevent the spilled oil from spreading and

*Fig. 35. (photo below) The Marine Oil Spill Response Corporation has facilities in U.S. coastal areas where petroleum is produced or transported. Here a floating boom keeps the spilled oil from spreading and confines it while a surface vacuum device recovers the oil and pumps it into tanks in the blue recovery vessel.*

Fig. 36

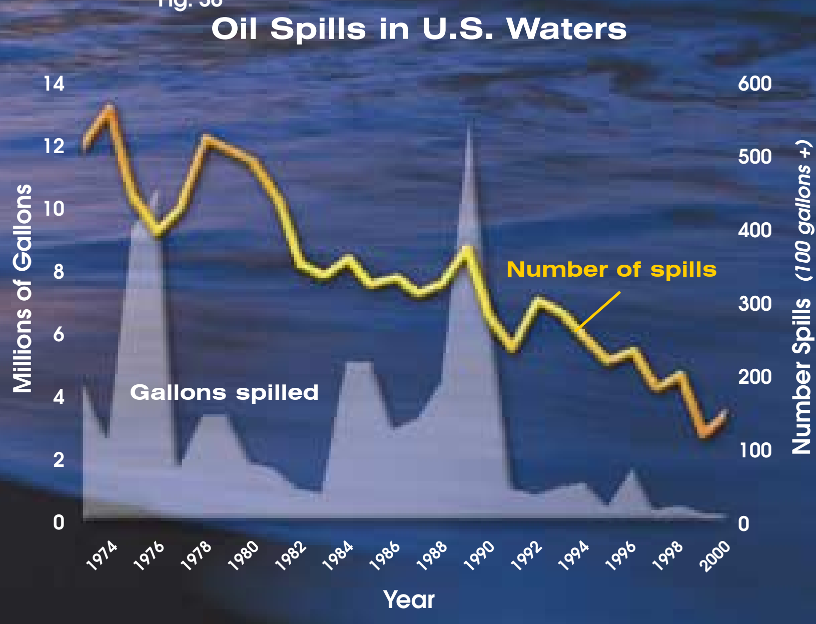



*Fig. 36. Marine oil spills in U.S. waters have decreased both in number and size.*

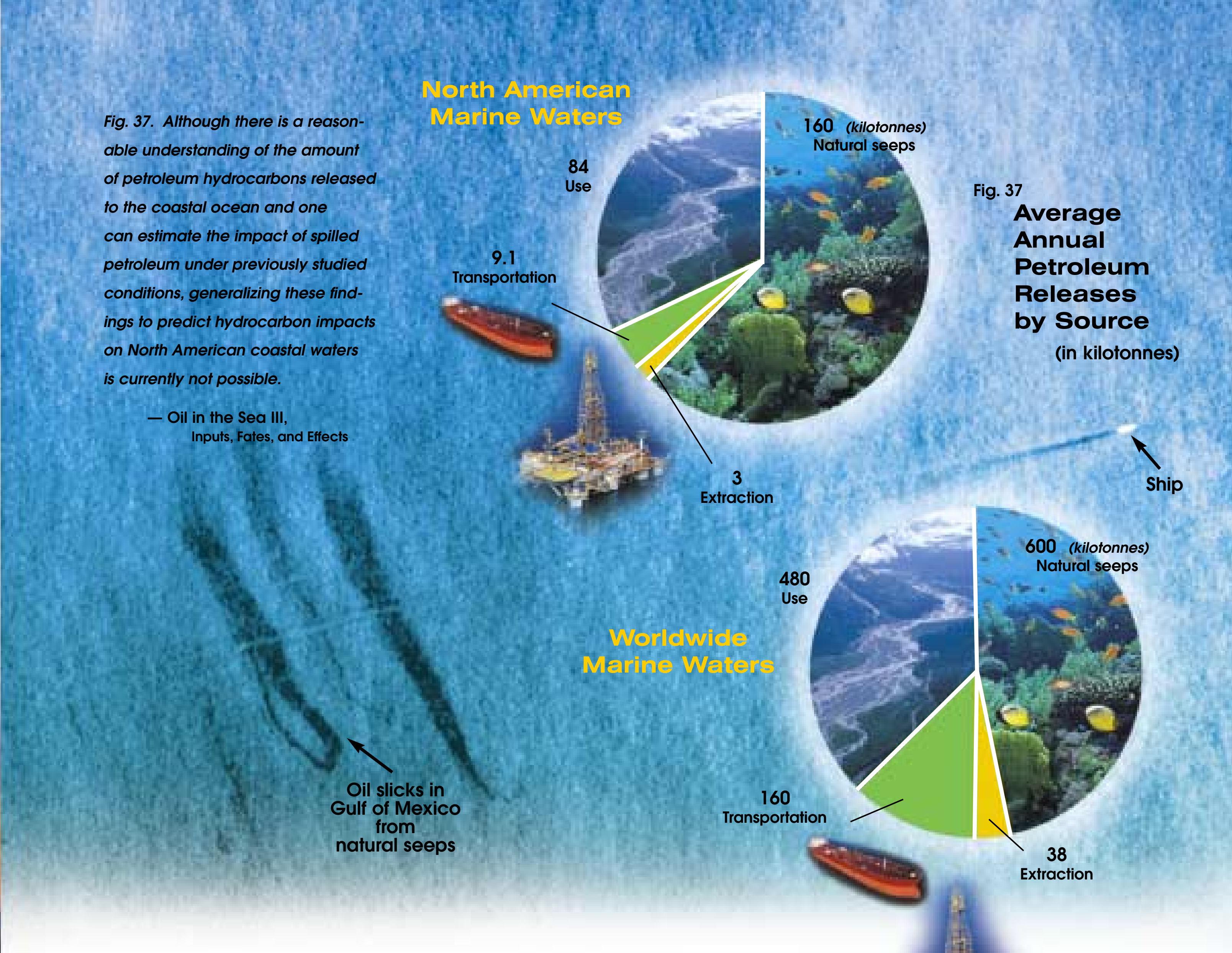



*Fig. 37. Although there is a reasonable understanding of the amount of petroleum hydrocarbons released to the coastal ocean and one can estimate the impact of spilled petroleum under previously studied conditions, generalizing these findings to predict hydrocarbon impacts on North American coastal waters is currently not possible.*

— Oil in the Sea III, Inputs, Fates, and Effects

to confine it for recovery. With most of the oil removed by skimming or adsorption, the remaining oil is left to naturally degrade. Volatile components evaporate and the other components disperse or are consumed by microorganisms. Dispersants can be applied to help break up the oil spill. The U.S. Coast Guard and the petroleum industry are also investigating controlled burns of oil spills to eliminate them before they can come ashore and impact sensitive ecosystems.

The combination of safe-operator training procedures, improvements in navigation standards, and mechanical design enhancements all seem to be working, as shown by the decline in frequency and size of tanker spills since 1974 (Fig. 36). The most current data for oil spills in U.S. waters show that less than 200 barrels (8,400 gallons) were spilled during 1999. This amount is only 0.0007 percent of the more than 3 billion barrels that were delivered to destinations in 1999. No large spills have occurred in U.S. waters since 1991. Completely preventing tanker spills is a continuing challenge, but these general trends are very encouraging. Overall, transporatation-related spills are small compared to other sources of petroleum in marine waters (Fig. 37).

## Pipelines

The United States has about 2.2 million miles of pipelines to gather and transport petroleum to refineries and to distribute finished products to population (Fig. 38a/b). Except for the largest tanker vessels, pipelines are the most economical means to move crude oil and products. For example, it costs about 3 cents a gallon to transport petroleum product from Texas to New Jersey, a fraction of the cost of sending a letter the same distance. The Trans-Alaska pipeline, the largest in the United States, transports about a million barrels per day, roughly 17 percent of the daily crude oil production in this country. Submarine pipelines are used to collect and transport petroleum produced in offshore areas such as the Gulf of Mexico. Pipelines can move products at rates of up to 6 miles per hour, and it may take anywhere from a few days to several weeks for petroleum to be transported from an oil field to a refinery. It commonly takes from a week to 10 days for petroleum products to arrive in the New England states from Gulf Coast refineries.

*Leaks are the principal environmental concern associated with pipeline transport of petroleum.* If leaks are not detected and repaired, they can contaminate soils and water. More importantly, uncontrolled leaks can lead to catastrophic explosions and fires that injure or kill nearby people. Preventing leaks and related accidents is a fundamental challenge to safe and environmentally sound pipeline management (Fig. 38c/d).

Most pipelines are underground and can therefore be difficult to locate precisely. This makes them especially vulnerable to damage by construction and utility workers who commonly excavate for other purposes. To help prevent these accidents, surface markings identify the positions of pipelines and pipeline operators maintain information centers that can assist in locating underground pipelines. It is possible to detect and map the location of underground pipelines with special field devices, and it is necessary to map all buried pipelines near a construction site before excavation begins. Construction permits and local regulations require such surveys in an effort to minimize the number of construction-related pipeline leaks.

**Dig safely**
**1-888-258-0808**

Another cause of pipeline spills is flaws in the materials from which the pipe is made. These flaws can be due to corrosion and wear during use or may result from original construction problems. To control corrosion, pipelines, like storage tanks, can be fitted with devices and coatings developed especially to minimize the effects of corrosion. **Welds** at pipeline joints have commonly been sources of pipeline leaks and fractures, but modern practices use x-ray analysis of each weld to ensure structural integrity. Monitoring and control devices detect and automatically shut down pipelines if leaks occur. Robotic devices called 'smart pigs' have been developed specifically to analyze interior pipeline surfaces. These devices travel inside pipelines and have sophisticated sensors that detect early signs of cracks or corrosion. If problems are detected, pipelines are shut down and repaired before a leak occurs. The number and size of spills have been decreasing, but all of the older pipelines have not been upgraded to

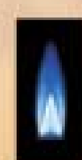
# natural gas

a

Fig. 38
## Petroleum Pipeline System

Natural Gas Pipeline Safety

c



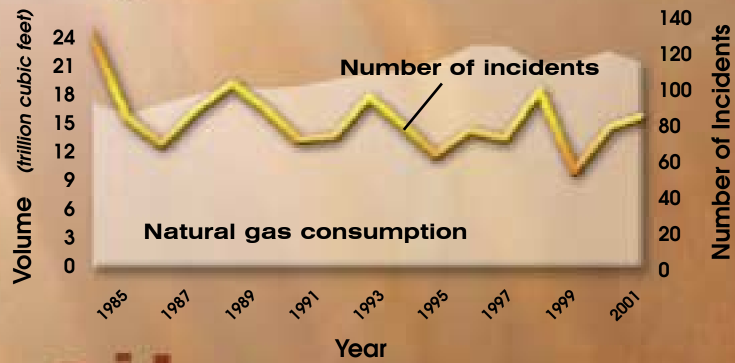



*Fig. 38 a/b. The United States has over two million miles of pipelines that make up a low-cost and efficient way to move natural gas (a) and crude oil (b).*

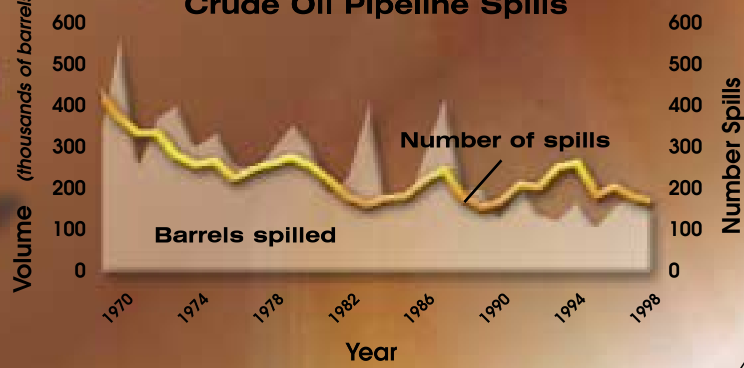
# oil


b

*Fig. 38 c/d. Crude oil pipeline spills have decreased in volume and number over the last three decades. Although average consumption of natural gas in the latest three year period (1999-2001), was almost 30% higher than the annual average over the first three years (1985-1987), the number of annual incidents involving fatalities or injuries has reduced slightly.*

Crude Oil Pipeline Spills

d




Office of Pipeline Safety
Department of Transportation

http://ops.dot.gov

the standards required of new ones. The pipeline industry, government, and regulators are currently considering new provisions that will further help ensure the safety of all pipelines.

## Getting Petroleum Products to Consumers

Getting petroleum products to consumers involves ships, barges, pipelines, trucks, and trains. The inland waterways that connect the major rivers of the eastern United States with the Atlantic seaboard and the Gulf Coast area are well suited for shallow-draft barge traffic. Barges serve many of the refineries and petrochemical plants in the Gulf Coast region and also provide a means for products like gasoline and diesel fuel to be moved along the Mississippi, Missouri, and Ohio rivers. Inland barges are usually coupled together and are moved by powerful 'pushboats' capable of traveling 5-6 miles per hour.

Tank trucks are a common sight on roads and highways throughout the United States. We are all familiar with accidents and their causes, such as the tanker truck that rolls over on a freeway and spills some of its cargo. Such spills are usually promptly contained and controlled, and we quickly resume our everyday activities. Trucks cannot transport more than a few thousand gallons at a time, but they are commonly the only way refined petroleum products can be delivered to remote locations and to areas where there are no pipelines or waterways. For example, tank trucks typically deliver gasoline to your local gas station.

Rail cars are used to move petroleum products that are too heavy to flow through pipelines or require special handling. Bulk lubricants, bitumen used in asphalt, the heavier grades of fuel oil, and related products such as molten sulfur are frequently transported by rail cars. Specialized rail cars may be equipped with heaters to prevent products from solidifying and to make discharging the cargo easier. The largest rail cars have capacities of approximately 1,000 barrels. Liquefied petroleum gases (LPG's) will volatilize and be lost if they are not maintained under specific pressure and temperature conditions. Pressurized rail cars allow LPG to be moved readily.

Another less well-known concern involves leaks from storage facilities such as underground gasoline tanks. It may surprise you to learn that consumer-controlled

facilities scattered across our nation, such as vehicle fuel tanks, home-heating oil tanks, generating-plant fuel tanks, farm-fuel storage tanks, and other small-capacity storage facilities contained an estimated 63 million barrels of petroleum products in 1998. It is important that everyone who uses petroleum products take care to prevent petroleum spills at all scales. Congress added Underground Storage Tank (UST) provisions to existing environmental regulations in 1984. This was done to help minimize possible contamination of aquifers by leaking UST's. There are about 700,000 UST's in the U. S. today, and they are routinely inspected to ensure that they are not accidentally leaking product underground.

*Many old storage tanks at gas stations have developed leaks that locally contaminate soil or groundwater.* All activities associated with petroleum and products made from it involve storage tanks. Such tanks are also used by consumers. Storage tanks are of various sizes and shapes, but two types are common. Above ground storage tanks can hold tens of thousands of barrels of petroleum products, and they are commonly used at production, transportation and refining facilities (Fig. 39). The other common type is the underground storage tank like those typically used at gasoline stations. To reduce the possibility of leaks and spills as well as the loss of volatile compounds to the atmosphere, both types of tanks have been extensively upgraded in recent years.

- To protect against corrosion, a common source of leaks, both types of tanks must now be protected with high-tech coatings or liners. Steel tanks can also be protected with cathodic protection systems, in which a weak electrical current prevents corrosion.
- Many spills occur during tank filling. As a preventative measure, alarms now warn operators when tanks are becoming full, and tanks are equipped with automatic shut off valves to prevent overfilling. Operators must receive training on the proper procedures to follow when tanks are being filled.
- Tanks must have catchment basins, dike walls, or double bottoms to act as containment safeguards against leaks and spills. In addition, systems are available that can monitor soil and groundwater underneath tanks for trace amounts of petroleum or product. These systems signal the operator if a problem exists.
- Tanks are routinely inspected and "tightness tested" to ensure structural integrity. They also have monitors that continuously monitor tank levels and can alert operators if a tank is losing fluids. These monitors detect losses as small as one-tenth of a gallon per hour.
- Tanks must be fitted with vapor recovery units to prevent volatile compounds from escaping into the atmosphere.

*Fig. 39. Storage tanks can hold hundreds of thousands of gallons of petroleum products.*

# PROVIDING SOUND STEWARDSHIP 5

How much longer our petroleum resources last depends a lot on us, the consumers. Conservation and recycling programs can extend the life of vital petroleum resources for future generations and reduce waste and emissions that impact the environment. We should support efforts to get better fuel efficiency in our vehicles, improved public transportation systems, and increased energy efficiency in our homes and industries. Increasing our energy efficiency by 10 percent on a nation-wide scale is equivalent to finding almost 2 million barrels of new oil reserves each day!

Our future petroleum operations should continue the trends of increased productivity and decreased environmental impacts that have developed in recent years. We can maximize our recovery of petroleum from oil and natural gas fields, decrease the frequency and size of spills wherever they may occur, and build and operate the world's safest and most efficient refineries. In the United States, we use more petroleum products per person than anywhere else in the world. This high level of consumption brings many benefits, but it also brings with it an extra level of responsibility to be prudent consumers and sound stewards of petroleum resources. A citizenry that is well informed on the environmental aspects of their most important energy sources helps assure that future industrial and consumer activities will be responsive to environmental concerns.

## Starting Sound Stewardship at Home

Consumers increasingly demand products that are safe to use and are less harmful to the environment. Such demands reflect the growing level of sensitivity to environmental issues in this country and demonstrate that striving for energy efficiency is a worthy goal for everyone. Better home insulation, more efficient lighting, and power-conserving appliances are examples from our homes. Supporting and using mass transit systems is another example. Many communities now provide mechanisms for recycling household wastes including petroleum-based plastics and used motor oil. If you think that the role you can play as an individual is not important, consider the following example.

The use of petroleum for lubrication in engines and equipment is well known. Nearly everyone has changed the oil in a car and fully understands that dirty oil makes bad


*Fig. 40. Many communities provide drop off centers for used motor oil. Virtually all of the used motor oil collected by service stations and automotive service centers is recycled.*

things happen to an engine! As a result, 600 million gallons of motor oil are sold annually in the United States. About half of that is sold to individuals who change their own oil. The other half is used by service stations and automotive service centers. Virtually all of the used motor oil collected by service stations and automotive service centers is recycled. However, the same cannot be said of many do-it-yourselfers — what happens to their used motor oil?

*Millions of gallons of used motor oil are disposed of improperly by individuals who change their own oil.* This oil is typically improperly placed in landfills, poured down storm drains, or dumped on the ground. Improperly discarded motor oil can contaminate soils, get into drinking water supplies or into rivers, lakes and even the ocean. About 175 million gallons of used motor oil are improperly disposed of each year. This is a huge problem that can be readily avoided. People should get in the habit of taking their used motor oil to one of the tens of thousands of drop-off points developed for this purpose (Fig. 40).

Everyone can help, and individual participation does make a difference. Consider this: two gallons of recycled motor oil can generate enough electricity to run the average household for a day, cook 48 meals in a microwave, blow hair dry 216 times, or operate a television set for 180 hours.

Numerous state and local regulations and ordinances also address petroleum in the environment. These can be equivalent to federal regulations or they may be more stringent. In some cases, the federal government has delegated regulatory responsibilities and authority to the states. However, the states are subject to federal intervention if they do not effectively enforce applicable statutes. In such cases, this may also include enforcement-related activities.

State-mandated environmental programs have a major impact on site-specific petroleum-related activities. For example, in order to evaluate potential petroleum contamination, the California Regional Water Quality Control Board in the Los Angeles region enacted an order that required all refineries and major storage facilities within its jurisdiction to characterize subsurface geologic, hydrogeologic, and environmental conditions underlying their respective properties. Where contamination was found, refiners were required to initiate recovery of lost product, and implement soil and groundwater remediation programs. These activities were carried out at major costs to refineries and storage facilities, but they resulted in significant cleanup programs and elimination of many troublesome contaminated sites.

## Regulatory Foundations of Stewardship

Federal, state, and local regulations affect every aspect of petroleum operations. Most oil producing states regulated petroleum activities for many years before federal organizations like the Department of Energy and the Environmental Protection Agency were created. Thus many federal regulations are rooted in older state laws and regulations that first recognized and dealt with environmental concerns. Regulatory emphasis was initially directed toward larger industries and those operations that generated large volumes of potential wastes. Initial regulations included permit requirements, stringent tracking and reporting procedures, and fines and penalties for noncompliance. There has been significant growth in the number of regulations that affect individuals as well as companies. Emission controls on vehicles and disposal requirements for waste motor oil are examples of this trend. Some of the more important federal regulations are listed below.

- The **Migratory Bird Treaty Act (MBTA)** and the **Endangered Species Act (ESA)** were established to protect wildlife in private and industrial environments.

- The **Outer Continental Shelf Lands Act (OCSLA)** protects submerged lands adjacent to the United States.

- The **Spill Prevention Control and Countermeasures (SPCC), Oil Pollution Act (OPA), Federal Water Pollution Control Act Amendments (FWPCA),** and the **Act to Prevent Pollution from Ships** were enacted to protect water quality.

- The **Resource, Conservation and Recovery Act (RCRA)** manages and controls hazardous wastes, the **Toxic Substance Control Act (TSCA)** guides handling and use of chemical substances, and the **Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)** and **Superfund Amendments and Reauthorization Act (SARA)** ensures that major releases of hazardous materials are cleaned up.

- The **Pipeline Safety Act (PSA)** and other regulations under the Department of Transportation (DOT) provide for the safe transportation of hazardous liquids and materials, and the **Hazardous Communication Standard (HAZCOM)** and **Hazardous Waste Operations and Emergency Response Standard (HAZWOPER)** protect workers in industrial environments.

- The **Oil Pollution Act (OPA)** was enacted in 1990 to reduce the risk of large oil spills, especially from tankers. This is the legislation that requires tankers operating in waters of the United States to have double hulls by 2015.

- The **Federal Land Policy And Management Act of 1976** requires the public lands to be managed in a manner that will protect the quality of scientific, scenic, historical, ecological, environmental air and atmospheric, water resources, and archeological values; that, where appropriate, will preserve and protect certain public lands in their natural condition; that will provide food and habitat for fish and wildlife and domestic animals; and that will provide for outdoor recreation and human occupancy and use.

Fig. 41

## Comparison of Growth Areas and Emissions

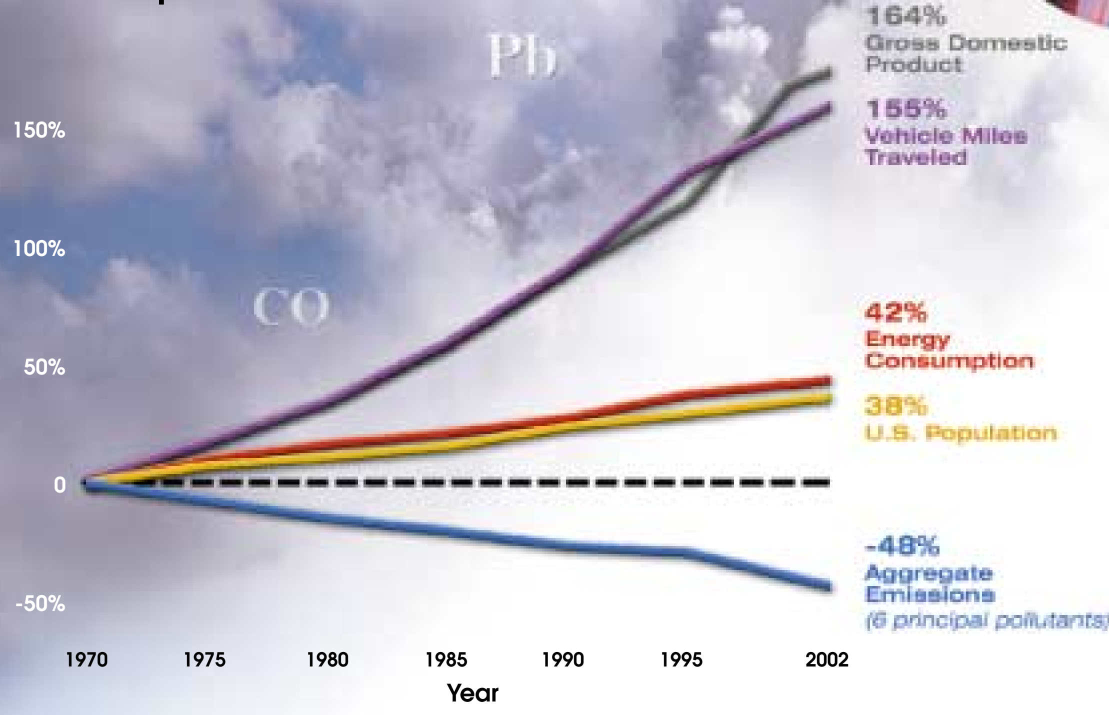



*Fig. 41. Although gross domestic product, vehicle miles traveled, energy consumption, and U.S. population increased significantly between 1970 and 2002, the Environmental Protection Agency estimates that total emissions of the six principal air pollutants decreased 25% during this period.*

## Emissions Examples

Using petroleum for heating, electricity generation, and transportation requires combustion to convert oil and natural gas into forms of energy. Combustion causes the more complex hydrocarbon compounds in petroleum to break down and produces exhaust gases that contain carbon dioxide ($CO_2$), carbon monoxide (CO), water vapor ($H_2O$), sulfur dioxide ($SO_2$), nitrogen dioxide ($NO_2$), and very fine particulate matter (soot). These exhaust gases, and other volatile petroleum components that evaporate and inadvertently escape to the atmosphere, such as at gasoline stations, can affect air quality.

*Air-quality degradation and smog development in some of our cities is largely caused by emissions from the tailpipes of our cars and trucks. There is increasing concern that lawnmowers, weedeaters, and pleasure craft may be polluting the air more than cars and trucks.* Smog, a mixture of smoke and fog, consists of many components, including sulfur oxides, nitrous oxides, ozone, carbon monoxide, carbon dioxide, water, and volatile hydrocarbon molecules. Some of the air-quality impacts become serious health concerns in urban areas. Increased incidence of respiratory stress and even death for people with heart or lung disease accompanies smog episodes.

To reduce emissions and protect air quality, changes in both vehicle design and gasoline formulation have been implemented:

- Transportation fuels have been reformulated over the years so that they contain less sulfur and volatile hydrocarbon components, both of which are major contributors to smog. Introduction of these fuels and improvements in internal combustion engines result in more complete combustion. This leads to improvements in vehicle efficiency and reductions in tailpipe emissions.

- Catalytic converters were installed on vehicles to reduce emissions. Catalytic converters convert carbon monoxide, hydrocarbon components, and nitrous oxides into carbon dioxide, nitrogen gas, and water vapor.
- Vehicles get better mileage, mainly due to improvements in engine efficiency and the development of lighter cars and trucks.

These changes have had positive results. Even though we more than doubled the miles we drove between 1970 and 2002, the Environmental Protection Agency estimates that total highway vehicle emissions declined by 25 percent (Fig. 41).

However, we can still do better (Fig. 42). Hybrid electric/gasoline cars can easily triple fuel efficiency and the rapidly developing **fuel-cell** technologies promise even greater breakthroughs. Fuel cells run on hydrogen by stripping it of its electrons and promoting electrochemical reactions which, in turn, drive an electric motor. The hydrogen atom then combines with oxygen in the air to make water vapor, the only emission generated. Fuel cells won't completely replace petroleum fuels, because certain hydrocarbons, such as hydrogen-rich methane, are excellent sources of the hydrogen needed by fuel cells.

*Carbon dioxide, produced by the combustion of all petroleum products, is a greenhouse gas. It is a component of the atmosphere that lowers the amount of the Sun's energy that is reflected from Earth and therefore could be an influence on global climate.* Through geologic time, Earth's climate and atmosphere evolved and changed. Scientists have determined that Earth's climate has been both warmer and colder than it is today due to natural changes in the atmosphere, the distribution of land masses and oceans, and the amount of solar radiation reaching Earth.

Scientists continue to debate whether human activity is contributing to making the Earth's atmosphere warmer. The key observation is that the concentration of $CO_2$ and other greenhouse gases in the atmosphere has risen dramatically during the past 50 years and that annual global average temperatures have also been rising. The debate centers on the possible cause of this warming, whether it will continue, and whether there may be important negative impacts from human society on global climate change such as rising sea levels and increased desertification.

Some scientists have concluded that rising atmospheric $CO_2$, resulting in part from the burning of oil, natural gas, and coal, has contributed to the observed surface air temperature increases. Although scientists have shown that $CO_2$ and temperature levels have both been higher in the geologic past, the present concerns center on the rate of increase of $CO_2$ concentrations and in global average temperature. The debate will continue, supported by ongoing and more extensive observations of atmospheric temperatures, analysis of historical records, and improved models for analyzing global climate. Scientists are divided as to whether data already available are a cause for concern. Global climate change and all of the related issues will also continue to be debated. The uncertainties surrounding these debates will make it challenging to be an up-to-date and informed observer. However, these are discussions that deserve our attention and warrant our best efforts to understand.


*Fig. 42. As new emissions standards for vehicles are implemented, it will take 28 new cars to equal the pollution emitted from a single 1960's era car.*

It is clear that the world's use of hydrocarbons — oil, natural gas, and coal — does release significant amounts of $CO_2$ to the environment. Although $CO_2$ levels in the geologic past — even before humans populated the planet — have been both higher and lower than those of today, it seems prudent for us to become better at minimizing them. The economics associated with curtailing $CO_2$ emissions will undoubtedly be a major consideration as to whether the United States will develop or participate in such a program. There is current interest in $CO_2$ sequestration possibilities such as injection into deep saline aquifers or the oceans. Additionally, there is ongoing research to assess whether $CO_2$ can be an economically viable means to recover residual oil from conventional fields or can enhance gas production from coal.

## Balancing Our Needs

Conventional petroleum resources will continue to be important well into the future, but we shall increasingly need to develop unconventional resources that are presently not economically feasible to use. Both conventional and unconventional resources, such as **gas hydrates** and **oil shale**, occur in many parts of the world. We will need to come to a shared understanding of the role of these resources and how they can be developed in balance with other values. The conflict between petroleum development and preservation of other resources such as wilderness is an active debate in the United States that deserves the attention of an informed populace. These debates can be most productive when the affected population has an understanding of the basic issues involved and actively seeks to bring such understanding to the decision-making process.

The most prominent contemporary example is the Arctic National Wildlife Refuge (ANWR) in Alaska. About 8 percent of the 19 million acres in ANWR, on the Arctic coastal plain, is prospective for large petroleum accumulations, but this general area is where the caribou have their calves each year. Also, ANWR is relatively undeveloped and as close to pristine wilderness as possible in our country. The conflict between development and preservation pits developers against environmentalists, the State of Alaska against the federal government, and local native groups against one another. For those at the extremes of this argument, it is simple — development versus preservation. For those somewhere else along the spectrum, the issue is complicated.
As concerned citizens we will need to stay engaged in efforts to remain current on these matters and then support the best plan of action.

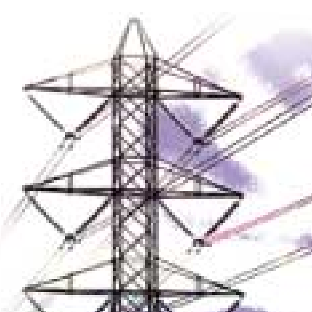
Debates over development versus preservation are important and they will continue — ANWR, offshore California, offshore Florida, and access to public lands in the Rocky Mountain region are just today's examples. But one thing is clear — technological innovations have and will continue to make development increasingly compatible with the environment. And both energy supplies and a protected environment are needed to maintain our quality of life.

To supply the energy needed by increasing populations and expanding economies worldwide, future demand for petroleum fuels and consumer products will be even greater than it is today. Petroleum will remain an essential part of our energy mix for decades to come. Current proven world petroleum reserves could last several more decades. With new discoveries and development of more unconventional sources of petroleum, such as **coalbed methane**, basin centered gas, gas hydrates, oil shales, and **tar sands**, significant supplies of oil and natural gas should meet our needs throughout the transition to future energy sources.

If our future does become one where we do not need petroleum resources from environmentally sensitive areas, it will be at least in part because we have developed new energy efficient technologies and alternative energy sources such as solar, wind, tidal, and even nuclear (Fig. 43). We should support investments in research that are needed to make these promising technologies important parts of our energy future. Fuel cells, for example, could replace the internal combustion engine in the future and drastically reduce our dependence on petroleum. By aggressively pursuing new technology development, our future can be one of gradual transitions to new ways of obtaining and using energy. In the meantime, we will continue to need our valuable petroleum resources, resources that we can discover, produce, and use in environmentally responsible ways.

We know that oil and natural gas are finite resources. Global production will decline over time, and alternative energy sources will be developed to first augment, and then replace oil and natural gas. It is in our best interest to follow sound practices that will ensure wise use of our remaining petroleum resources. We must pursue means to extend oil and gas development activities while minimizing related environmental impact. It is also necessary that we continue to develop new petroleum-derived products that have progressively less effect on even very delicate environments. Extending the life of these valuable nonrenewable resources, protecting the environment, and easing the transition to alternative energy sources for future generations are challenges we face as citizens of the Earth.

*Fig. 43. The use of petroleum and natural gas will grow progressively smaller as global supplies are consumed. Future energy supplies for the United States will come from a variety of sources. Geothermal, wind, solar, and nuclear energy will all play key roles in supplying our future energy needs.*



# Glossary

**aquifer** An underground body of rock that contains enough saturated permeable material to conduct groundwater and provide useful quantities of water to a well or a spring.

**catalyst** A material that affects the rate of a chemical reaction but does not participate in it. A catalyst remains chemically unaltered while it speeds up or slows down a chemical reaction.

**coalbed methane** Methane adsorped onto the surface of coal and which may be produced when pressure conditions, primarily due to overlying water, are sufficiently reduced to allow the gas to be released.

**cracking** Breaking complex chemical compounds, such as hydrocarbons, into smaller and more simple ones.

**cuttings** Small pieces of rock broken away by the rotary bit during drilling and removed from the bore hole by heavy viscous drilling mud.

**directional drilling** Deliberately deviating a well bore from the path it would normally takein order to reach targets that cannot be drilled using vertical well bores or to contact greater reservoir volume.

**distillation** A purification process that converts a liquid to a gas and then cooling it so that it condenses back to a liquid.

**drilling mud** The viscous fluid that circulates through a drill bit to cool it and flushes rock particles up to the surface.

**formation water** Water present in a water-bearing formation under natural conditions. Formation water that was trapped in the pores of sedimentary rocks as they formed is saline.

**fuel cell** An electrochemical cell in which the energy of a reaction, such as that between hydrogen and oxygen, yields electricity, water, and heat.

**gas hydrate** An ice-like crystalline solid formed from water and which incorporates small gaseous molecules, such as methane, into the voids that occur in its structure. Methane hydrates occur below the sediment-water interface in marine settings and at shallow depth in polar terrestrial locations.

**hydrocarbon** A compound that consists solely of carbon and hydrogen.

**land farming** Aerating, tilling, or otherwise amending petroleum-contaminated soil so that biological and/or chemical processes act to remove hydrocarbons, generally converting them to carbon dioxide and water.

**logging** The use of downhole devices to measure selected physical properties and provide information related to the presence of oil and natural gas in a well.

**oil shale** A sedimentary rock composed of clay size (0.00016 inch or 0.0039 millimeters) mineral particles and enough organic matter so that it yields oil and gas when heated.

**permeability** The property or capacity of a porous rock, sediment, or soil for transmitting a fluid; it is a measure of the relative ease of fluid flow under unequal pressure and is a function only of the medium.

**petroleum** A naturally occurring mixture primarily containing hydrocarbons but may contain minor amounts of non-hydrocarbon compounds. The mixture may be a gas, liquid, or solid.

**petroleum source rock** A fine-grained organic-rich sedimentary rock that generates petroleum when buried in sedimentary basins and exposed to elevated temperatures there.

**reflection seismology** A geophysical technique based on transmission of sound waves from the surface into the Earth where it is reflected back by rock layers. By knowing the velocity of the sound waves and measuring the arrival time of the reflections, underground rock layers can be mapped

**reserves** Known sources of oil or gas that are extractable using current technologies at current prices.

**reservoir rock** An underground body of rock that has sufficient porosity and permeability to store or accumulate oil or gas (or both).

**resources** Potentially recoverable oil and gas deposits that are not currently produced because it is not cost effective to do so.

**sedimentary basin** A depression in the uppermost part of the Earth where sediments accumulate.

**seep** An area, generally small, where oil, gas, or water slowly percolates to the land surface.

**shale** A fine-grained sedimentary rock formed by consolidation of clay and silt particles. The rocks formed by this process are relatively impermeable.

**tar sand** Loose or poorly consolidated sand grains held together by naturally occurring bitumen or asphalt-like hydrocarbon material. If the bitumen can be economically removed from mineral matter, it can be blended with other organic material and refined to yield a range of products.

**trap** A barrier to the upward movement of oil or gas, allowing either or both to accumulate. Traps generally include porous and permeable reservoir rocks that hold petroleum and low-permeability shales that prevent fluid movement.

**weld** The area of a pipeline where two pieces were joined by melting and fusing them together. Pipeline welds are subjected to x-ray inspection to ensure physical integrity and thus reduce the possibility of leaks.

# Credits

**Front Cover** — Drilling Platform (Noble Drilling Corp.); Mountains (Corbis); Pelicans (Comstock); Caribou (Hemera); Shore, seal, dolphins and fish (Digital Vision).

**Inside Front Cover/Title Page** — Bird (Comstock); Oil derrick workers, refinery and pipelines (Corbis).

**Contents** — Landscape (Digital Vision).

**Foreword/Preface** — Ship (Noble Drilling Corp.); Polar bear (Digital Vision); High tech oil exploration (WesternGeco).

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- Page 8 — How Big is a Barrel, data (DOE/EIA). Fig. 1, Jet airplane, balloons, sunglasses, crayons, roller blader, red sports car, paint brushes, purse, perfume, speed boat, prescription drugs and train (Hemera); Compact disc (Comstock); Power lines, clothing shops and gas pump (Corbis).
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**Chapter 4** — Opening — Pipelines, oil tanker, truck and train (Corbis).
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**Inside Back Cover** — Mountain landscape (Corbis).

**Back Cover** — Drilling rig and Dallas skyline (Corbis).

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# Sources of Additional Infomation

The organizations listed here are only a fraction of the additional sources of energy resources information. Listings for state geological surveys appear on the next page.

**American Association of Petroleum Geologists**
www.aapg.org/

**American Petroleum Institute**
api-ec.api.org/

**Bureau of Land Management**
www.blm.gov/

**Environmental Protection Agency**
www.epa.gov/

**Environmental Research Foundation**
www.rachel.org/home_eng.htm

**Interstate Natural Gas Association of America**
www.ingaa.org/

**Minerals Management Service**
www.mms.gov/

**National Energy Foundation**
www.nef1.org/

**Paleontological Research Institution**
www.priweb.org/ed/pgws/index.html

**Society of Petroleum Engineers**
www.spe.org/

**USDA Forest Service**
www.fs.fed.us/geology/

**U.S. Department of Energy**
www.doe.gov/ and www.eia.doe.gov/

**U.S. Department of Transportation**
www.dot.gov/

**U.S. Geological Survey**
www.usgs.gov/

# S T A T E   G E O L O G I C A L   S U R V E Y S

**Geological Survey of Alabama**
www.gsa.state.al.us

**Alaska Division of Geological and Geophysical Surveys**
wwwdggs.dnr.state.ak.us/

**Arizona Geological Survey**
www.azgs.state.az.us

**Arkansas Geological Commission**
www.state.ar.us/agc/agc.htm

**California Geological Survey**
www.consrv.ca.gov/cgs/

**Colorado Geological Survey**
http://geosurvey.state.co.us/

**Connecticut Geological and Natural History Survey**
http://dep.state.ct.us/cgnhs/

**Delaware Geological Survey**
www.udel.edu/dgs/index.html

**Florida Geological Survey**
www.dep.state.fl.us/geology/

**Georgia Geologic Survey Branch**
www.dnr.state.ga.us/dnr/environ/aboutepd_files/branches_files/gsb.htm

**Hawaii Geological Survey**
www.state.hi.us/dlnr/cwrm

**Idaho Geological Survey**
www.idahogeology.org/

**Illinois State Geological Survey**
www.isgs.uiuc.edu/

**Indiana Geological Survey**
http://igs.indiana.edu/

**Iowa Geological Survey Bureau/IDNR**
www.igsb.uiowa.edu/

**Kansas Geological Survey**
www.kgs.ku.edu/

**Kentucky Geological Survey**
www.uky.edu/KGS/home.htm

**Louisiana Geological Survey**
www.lgs.lsu.edu/

**Maine Geological Survey**
www.state.me.us/doc/nrimc/mgs/mgs.htm

**Maryland Geological Survey**
www.mgs.md.gov/

**Massachusetts Geological Survey**
www.state.ma.us/envir/eoea

**Michigan Geological Survey Division**
www.michigan.gov/deq/1,1607,7-135-3306_3334_3568—,00.html

**Minnesota Geological Survey**
www.geo.umn.edu/mgs/

**Mississippi Office of Geology**
www.deq.state.ms.us/

**Missouri Geological Survey and Resource Assessment Division**
www.dnr.state.mo.us/dgls/homedgls.htm

**Montana Bureau of Mines and Geology**
http://mbmgsun.mtech.edu/

**Nebraska Conservation and Survey Division**
http://csd.unl.edu/csd.htm

**Nevada Bureau of Mines and Geology**
www.nbmg.unr.edu

**New Hampshire Geological Survey**
www.des.state.nh.us/descover.htm

**New Jersey Geological Survey**
www.state.nj.us/dep/njgs/

**New Mexico Bureau of Geology and Mineral Resources**
www.geoinfo.nmt.edu

**New York State Geological Survey**
www.nysm.nysed.gov/geology.html

**North Carolina Geological Survey**
www.geology.enr.state.nc.us/

**North Dakota Geological Survey**
www.state.nd.us/ndgs/

**Ohio Division of Geological Survey**
www.ohiodnr.com/geosurvey/

**Oklahoma Geological Survey**
www.ou.edu/special/ogs-pttc/

**Oregon Department of Geology and Mineral Industries**
www.oregongeology.com/

**Pennsylvania Bureau of Topographic and Geologic Survey**
www.dcnr.state.pa.us/topogeo

**Puerto Rico Departamento de Recursos Naturales**
www.kgs.edu/AASG/puertorico.html

**Rhode Island Geological Survey**
www.uri.edu/cels/gel_home/ri_geological_survey.htm

**South Carolina Geological Survey**
water.dnr.state.sc.us/geology/geohome.htm

**South Dakota Geological Survey**
www.sdgs.usd.edu/

**Tennessee Division of Geology**
www.state.tn.us/environment/tdg/

**Texas Bureau of Economic Geology**
www.beg.utexas.edu/

**Utah Geological Survey**
http://geology.utah.gov/

**Vermont Geological Survey**
www.anr.state.vt.us/geology/vgshmpg.htm

**Virginia Division of Mineral Resources**
www.geology.state.va.us

**Washington Division of Geology and Earth Resources**
www.wa.gov/dnr/htdocs/ger/ger.html

**West Virginia Geological and Economic Survey**
www.wvgs.wvnet.edu/

**Wisconsin Geological and Natural History Survey**
www.uwex.edu/wgnhs/

**Wyoming State Geological Survey**
www.wsgsweb.uwyo.edu/

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Supporting GEOSCIENCES for the future

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The AGI Foundation was established more than a decade ago to assist the Institute in seeking funding and partnerships with foundations, corporations, other organizations, and individuals that share our commitment to create innovative Earth-science programs of benefit to all citizens. AGI's programs — focusing on education, worldwide information systems, government affairs, environmental awareness and other issues — offer new opportunities for geoscientists, enhance research capabilities of professional Earth scientists, and develop innovative education tools to expand the Earth-science knowledge base of all Americans, not just those who will choose geoscience as a career.

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# PETROLEUM
## and the Environment

**William E. Harrison**

**Stephen M. Testa**

Few of us ever think about petroleum as we're using common petrochemical products like a plastic cup or a plastic utensil. Yet many everyday products including CDs, computers, crayons, rayon, nylon, plastics, furniture wax, antihistamines, liquid detergent, vitamin capsules, hair dyes, deodorant, paint, glue, sunglasses, and trash bags all originate from petroleum. It usually takes increases in the price of gasoline, brownouts when electricity is in short supply, or an accident like an oil spill to focus our attention on petroleum and its impact on the environment. Concerned citizens recognize the need to manage both our petroleum resources and natural environments wisely. *Petroleum and the Environment*, the 6th publication in the AGI Environmental Awareness Series, provides an introduction to the major environmental concerns associated with petroleum exploration, production, transportation, and use.

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