Fundamentals of Petroleum

Fifth Edition

The University of Texas at Austin - Petroleum Extension Service

Contents

Units of Measurement

Throughout the world, two systems of measurement dominate: the English system and the metric system. Today, the United States is one of only a few countries that employ the English system.

The English system uses the pound as the unit of weight, the foot as the unit of length, and the gallon as the unit of capacity. In the English system, for example, 1 foot equals 12 inches, 1 yard equals 36 inches, and 1 mile equals 5,280 feet or 1,760 yards.

The metric system uses the gram as the unit of weight, the metre as the unit of length, and the litre as the unit of capacity. In the metric system, 1 metre equals 10 decimetres, 100 centimetres, or 1,000 millimetres. A kilometre equals 1,000 metres. The metric system, unlike the English system, uses a base of 10; thus, it is easy to convert from one unit to another. To convert from one unit to another in the English system, you must memorize or look up the values.

In the late 1970s, the Eleventh General Conference on Weights and Measures described and adopted the Systeme International (SI) d'Unites. Conference participants based the SI system on the metric system and designed it as an international standard of measurement.

The Rotary Drilling Series gives both English and SI units. And because the SI system employs the British spelling of many of the terms, the book follows those spelling rules as well. The unit of length, for example, is metre, not meter. (Note, however, that the unit of weight is gram, not gramme.)

To aid U.S. readers in making and understanding the conversion system, we include the table on the next page.

English-Units-to-SI-Units Conversion Factors

Quantity or Property	English Units	Multiply English Units By	To Obtain These SI Units
Length, depth, or height	inches (in.)	25.4	millimetres (mm)
		2.54	centimetres (cm)
	feet (ft)	0.3048	metres (m)
	yards (yd)	0.9144	metres (m)
	miles (mi)	1609.344	metres (m)
		1.61	kilometres (km)
Hole and pipe diameters, bit size	inches (in.)	25.4	millimetres (mm)
Drilling rate	feet per hour (ft/h)	0.3048	metres per hour (m/h)
Weight on bit	pounds (lb)	0.445	decanewtons (dN)
Nozzle size	32nds of an inch	0.8	millimetres (mm)
Volume	barrels (bbl)	0.159	cubic metres (m^3)
		159	litres (L)
	gallons per stroke (gal/stroke)	0.00379	cubic metres per stroke (m^3/stroke)
	ounces (oz)	29.57	millilitres (mL)
	cubic inches ($in.^3$)	16.387	cubic centimetres (cm^3)
	cubic feet (ft^3)	28.3169	litres (L)
		0.0283	cubic metres (m^3)
	quarts (qt)	0.9464	litres (L)
	gallons (gal)	3.7854	litres (L)
	gallons (gal)	0.00379	cubic metres (m^3)
	pounds per barrel (lb/bbl)	2.895	kilograms per cubic metre (kg/m^3)
	barrels per ton (bbl/tn)	0.175	cubic metres per tonne (m^3/t)
Pump output and flow rate	gallons per minute (gpm)	0.00379	cubic metres per minute (m^3/min)
	gallons per hour (gph)	0.00379	cubic metres per hour (m^3/h)
	barrels per stroke (bbl/stroke)	0.159	cubic metres per stroke (m^3/stroke)
	barrels per minute (bbl/min)	0.159	cubic metres per minute (m^3/min)
Pressure	pounds per square inch (psi)	6.895	kilopascals (kPa)
		0.006895	megapascals (MPa)
Temperature	degrees Fahrenheit (°F)	$\frac{°F - 32}{1.8}$	degrees Celsius (°C)
Mass (weight)	ounces (oz)	28.35	grams (g)
	pounds (lb)	453.59	grams (g)
		0.4536	kilograms (kg)
	tons (tn)	0.9072	tonnes (t)
	pounds per foot (lb/ft)	1.488	kilograms per metre (kg/m)
Mud weight	pounds per gallon (ppg)	119.82	kilograms per cubic metre (kg/m^3)
	pounds per cubic foot (lb/ft^3)	16.0	kilograms per cubic metre (kg/m^3)
Pressure gradient	pounds per square inch per foot (psi/ft)	22.621	kilopascals per metre (kPa/m)
Funnel viscosity	seconds per quart (s/qt)	1.057	seconds per litre (s/L)
Yield point	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Gel strength	pounds per 100 square feet (lb/100 ft^2)	0.48	pascals (Pa)
Filter cake thickness	32nds of an inch	0.8	millimetres (mm)
Power	horsepower (hp)	0.75	kilowatts (kW)
Area	square inches ($in.^2$)	6.45	square centimetres (cm^2)
	square feet (ft^2)	0.0929	square metres (m^2)
	square yards (yd^2)	0.8361	square metres (m^2)
	square miles (mi^2)	2.59	square kilometres (km^2)
	acre (ac)	0.40	hectare (ha)
Drilling line wear	ton-miles (tn•mi)	14.317	megajoules (MJ)
		1.459	tonne-kilometres (t•km)
Torque	foot-pounds (ft•lb)	1.3558	newton metres (N•m)

HOW TO USE THIS BOOK

It is recommended that this book be read in sequence first to absorb the full end-to-end story of petroleum, beginning with geology and ending with alternative energy sources. It can also be used as an ongoing reference for specific information on topics of interest.

- Chapter objectives, callouts, and summaries help highlight major points for readers.
- Hundreds of color images visually support the text to enhance learning.
- An index is included for convenience in looking up topics.
- Italicized terms are defined in *A Dictionary for the Oil and Gas Industry*, 2nd Edition, available as a separate product.
- Two reading formats are available for reader preference: print and e-book.
- A separate online assessment is also available to test learning comprehension. Readers who successfully complete the assessment will receive a *Certificate of Completion* and Continuing Education Credits (CEUs) that can be useful career advancement tools.
- A companion course aligned with this publication is also offered at the PETEX Houston and West Texas Training Centers and at client locations upon request.

Reader feedback is welcomed so we can continue to refine this publication for the benefit of all users. Please contact us with any corrections or revisions necessary for future editions. As always, PETEX strives to provide quality content to enhance industry workplace performance.

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Introduction

THE DEMAND FOR OIL

Oil is used in nearly every aspect of life from fuel for cars, trucks, and planes to plastics, clothing, food additives, and medicines. In fact, it is nearly impossible to find some aspect of modern lives that does not require or depend on oil. Without oil, there would be no global economy. Modern society cannot function without oil.

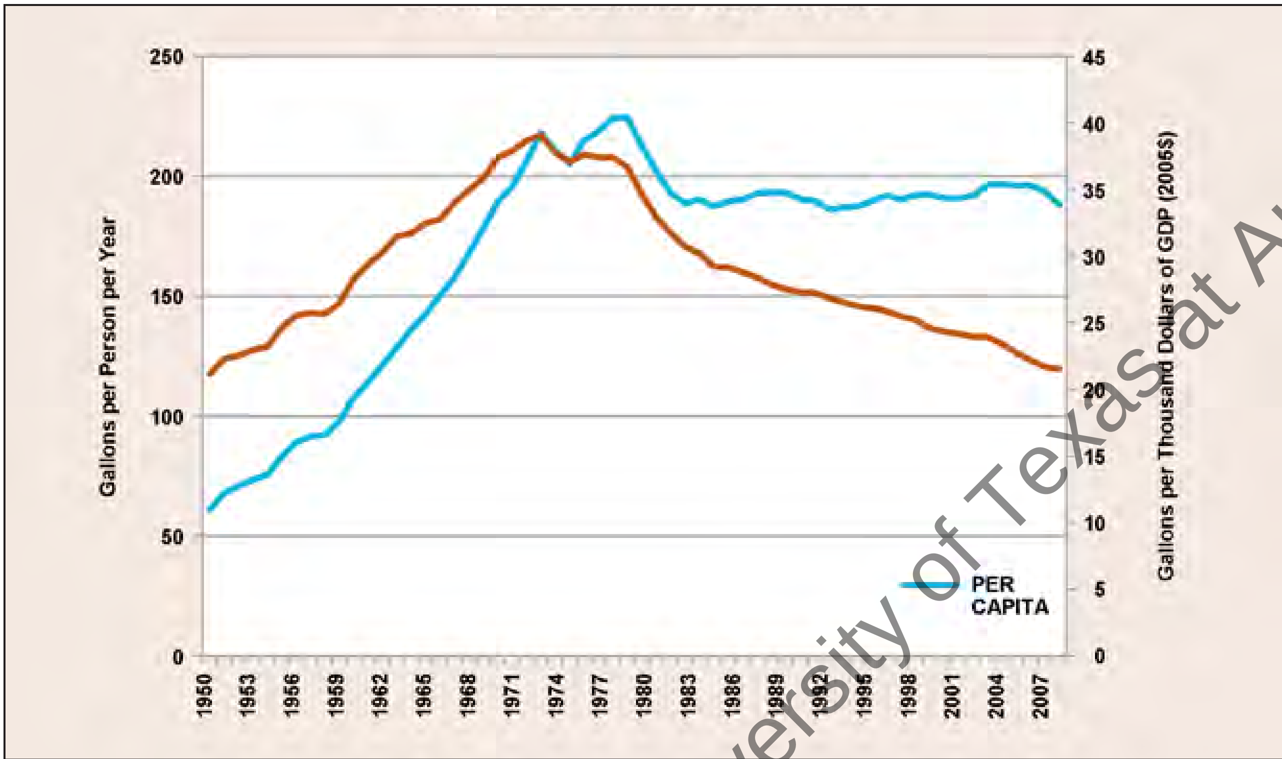
On average, every person in the world consumes about 195 gallons (738 litres) of oil per year. In the United States, consumption per person is five times that level, while in China it is about half the world average. Although oil is used for nearly everything, it is peoples' need to be mobile and the desire for more freedom of mobility that are the major forces driving oil demand today. As a result, more than half of oil consumption is used for transportation. Demand in developed countries is maturing, while economic growth in developing countries is dependent on oil as transportation systems and wealth grow.

The need for oil continues to increase. Demand has been rising steadily in nearly all regions of the world for the past 25 years. The demand for oil—the collective needs of the oil industry's final customers—drives all other aspects of the oil industry. These needs have changed over time and are expected to continue evolving as consumers and policies change. Changes in oil demand in the short and medium term (one to five years) are largely determined by price movements, economic growth, and weather. Over the longer term, demand is determined by end-user investment decisions and government policy.

In the past few years, growth in oil demand has slowed due to the impact of higher prices, and volume demand has fallen in 2008 and 2009 due to the effects of the global economic recession. But as economies around the world recover, so will oil demand. The rate of growth and the characteristics of demand are likely to change in the post-economic recovery.

Shares of Global Demand

Fuel Type		Regional Oil Demand		Sector Oil Demand	
Coal	26%	North America	30%	Residential/Commercial	12%
Oil	37%	South America	7%	Industry	8%
Gas	23%	Europe	20%	Feedstock	8%
Hydro	6%	Eurasia	5%	Transportation	52%
Nuclear	6%	Middle East	7%	Power Generation	7%
Renewable	1%	Asia	28%	Misc.	12%
		Africa	4%		

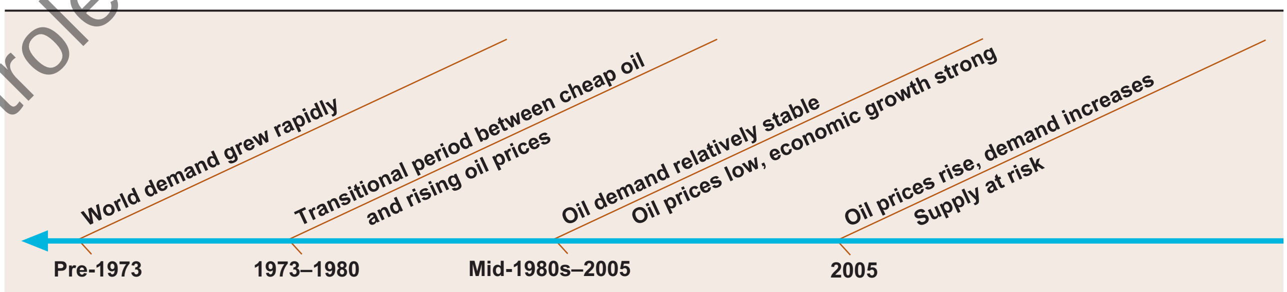


Global oil demand—key drivers

From Past to Present

The history of global oil demand can be divided into three distinct eras:

- **Pre-1973:** Driven by both economic and population growth, world oil demand grew quickly. Rapid industrialization and increasing populations with rising personal incomes combined with cheap abundant oil resulted in a steady rise in global oil demand. The relationships between economic growth, population growth, and oil demand growth were relatively stable.
- **1973 to 1980:** These years were a transition period from the pre-1973 era of cheap oil to a political and price environment characterized by high oil prices, a prevailing view that prices would continue to rise (to safeguard against running out of oil), and policies that would move major economics away from oil.

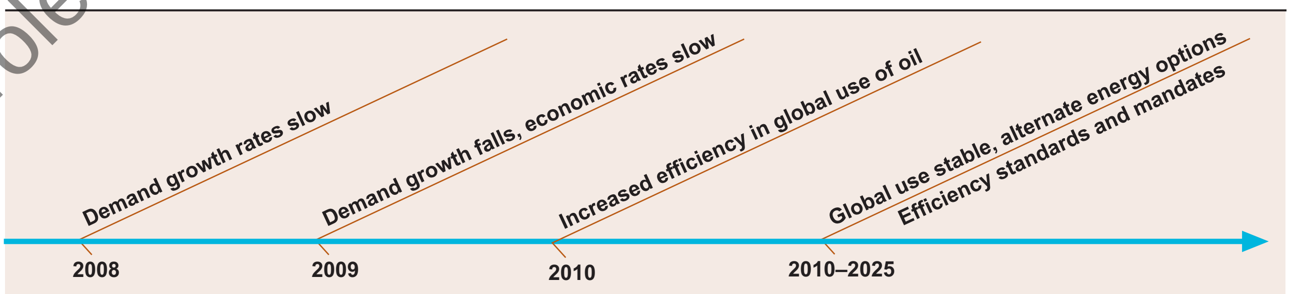


- **Mid-1980s to present:** Since the early to middle 1980s, oil demand had been in a period of relative stability. Oil prices were low and global economic growth was strong. However, the relationships had changed from previous periods. Trends for oil demand per person were flat, and oil demand per dollar of Gross Domestic Product (GDP) fell at a steady rate during this period.

Over the last 25 years, oil's importance to the global economy has been gradually declining:

- Oil use per dollar of GDP has declined at a steady rate, regardless of the rate of economic growth.
- Oil use per person worldwide has been stable for 25 years—between 190 and 200 gallons (719 and 757 litres) per person per year. While rising in some emerging markets, use per person has begun to decline in some major markets such as Japan and Germany.

Regardless of the various changes in oil consumption from one country to another or the rate of economic growth in emerging markets compared to developed economies, the stability in per-capita consumption of oil indicates that on average, world oil demand growth is largely driven by population growth. In some emerging market countries, combined population growth and economic growth are causing oil demand to rise, while demand is maturing and even falling in some developed countries. However, worldwide, the amount of oil needed to create $1,000 of economic growth has been declining steadily since the mid-1980s. In other words, the global economy is becoming more efficient in its use of oil, at a rate of about 1.5% per year. In 2010, it takes about 19 gallons (72 litres) of oil to create $1,000 of economic output. By comparison, it took nearly 40 gallons (151 litres) for the same economic output in the early 1970s.



From the early 1980s to about 2005, the price of oil on average was the price needed to work off the spare capacity in the system. This price level encouraged a rise in consumption and, at the same time, discouraged growth in oil production. During this period, events such as hurricanes, cold weather, wars, and accidents that typically impact oil markets had an impact on prices, but these effects were hardly noticed by consumers—at least not in a way that would alter demand patterns in any sustainable manner. Despite relatively low prices and strong economic growth, global oil demand grew at the same rate as population growth.

By 2005, the spare capacity of OPEC—the Organization of Petroleum Exporting Countries—and consequently, the spare capacity of the industry, was essentially zero. Very quickly, oil prices increased to levels unthinkable just a short time before. As demand increased or supply was suddenly perceived to be at risk, prices kept rising. There was no more spare capacity to bring online to meet market demand. As a result, prices shifted to reflect the price level needed to slow down or reduce oil demand. Events, such as hurricanes and political developments, had significant impact on *spot* (immediate) *prices* and consumer prices.

The years 2008 and 2009 might well be one of the rare major turning points in the history of oil demand. By 2008, signs of the impact of high oil prices on demand were beginning to materialize. Countries that subsidized consumer oil prices were raising prices, thereby causing demand growth rates to slow. U.S. consumers began to reduce gasoline consumption and air travel. By 2008, global oil demand growth had slowed to zero, and demand in 2009 fell 2.4 %—the largest fall in oil demand since 1980—as a result of the global economic recession and very high oil prices in 2008.

What Does the Future Hold?

As happened in the late 1970s and early 1980s, the oil industry is experiencing a once-in-a-generation level of change in demand for its products. The global energy picture and that of the United States are being reshaped by prices and politics to a degree not seen since the 1970s. Oil's recent past is unprecedented. Numerous events and developments have occurred in a relatively short period of time. Some individual factors will have significant implications for future oil demand, and taken collectively, impacts could have long-term implications unlike anything experienced in the past. Some examples of recent events and government actions are:

- Hurricanes that severely disrupt U.S. refinery production.
- Oil prices rising to $140 per barrel, causing U.S. retail gasoline prices to exceed $4 per gallon for much of the summer of 2008.
- Vehicle efficiency standards that passed in several of the world's major oil markets, including the United States, the European Union, Japan, and China, which are set to take effect over the next 10 to 15 years.

- Biofuel mandates and targets that displace oil from transportation fuels by 20% or more in the United States, India, the European Union, and Brazil, which are to be established by 2020. Several other countries have much smaller requirements.
- Regulations that reduce carbon emissions and have further implications for oil use.

It could be that oil demand is entering a new, fourth era. Over the next decade and beyond, oil use per dollar of GDP is likely to decline at a faster rate than during the past 25 years, and oil use per capita could begin to decline. As occurred in the 1970s, over the past few years, governments around the world have begun to enact policies to reduce oil demand. Around the world, major oil importing countries are adjusting their energy and environmental policies to guide countries to lower energy intensity, economic growth, and greater energy security. These actions are driven by two major forces: a concern that oil prices will return to the extreme levels of 2006 to 2008 and damage economic recovery and growth, and the need to reduce greenhouse gas emissions to address global warming.

For the first time since the beginning of the oil age, the cost of consuming oil might be higher that the economic benefit of its use. Governments around the world now agree that global climate change poses a real threat to mankind and must be addressed urgently. With transportation the largest single source of carbon dioxide emissions in the United States and second only to coal worldwide, reducing carbon emissions from transportation is a critical component in the effort to reduce greenhouse gas emissions. Reducing greenhouse gas emissions from oil means using less oil, either through higher efficiency or by using substitutes such as biofuels. Countries worldwide are doing both.

Efforts to reduce oil demand through legislation are now unprecedented in the history of oil use. Government initiatives are also supported by tax incentives and mandates that help ensure goals are met. In addition, as these changes gradually begin to impact overall oil demand in the oil-consuming countries of Japan, China, India, Brazil, and the United States, other countries might adopt similar measures, putting additional pressure on oil use around the world.

Pre-1973	1973-1980	Mid-1980s to 2010	2010 and Beyond
Increasing populations	Growth in global demand	Oil demand stabilizing	Unprecedented change
Rapid industrialization	Rising oil prices	Declining oil prices	Global recession
Rising personal incomes	Economic movement from oil	Strong economic growth	Impactful policies and events
Abundant cheap oil	Perceived supply shortage	Emerging energy alternatives	A new era of oil

Past experience is critical in helping us to form the basis for future decisions and plans. The oil industry has an abundance of data and information with which to analyze past oil demand and give insights about the future. But a key question of analysts today remains. Even with good data and analysis available, is the past a good indicator of the future of oil and energy demand? This and other questions will be discussed in the chapters that follow. While future oil demand growth is much less certain now than at nearly any time in the past 25 years, the oil industry and the study of energy markets promises to be more exciting and challenging than it has been in at least a generation.

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Kevin Lindemer has over twenty-five years of experience in the oil and downstream petroleum industries and is an expert on the global oil industry. He specializes in downstream refining and marketing operations and has worked on consulting and research projects in the energy, biofuels, and downstream oil business worldwide. He holds an MS in Agricultural and Applied Economics and a BS in Plant Pathology with emphasis in economics and chemistry.

PART 1
Exploration

The Authors

GEOLOGY

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Christopher Zahm is a leading expert in fractured reservoir characterization, including the interpretation of structural folds and faults in seismic. He works with both outcrops and subsurface data to build 3D geologic models used by the petroleum industry. Zahm teaches Petroleum Basin Evaluation and conducts research at the University's Reservoir Characterization Research Laboratory. His research focuses on predicting the distribution of faults and fractures in the subsurface to understand how these features influence fluid flow within petroleum reservoirs. Zahm's career includes key former positions at ConocoPhillips, iReservoir, Colorado School of Mines, and as a consultant to several independent oil and gas companies. He holds a BSC in Geology and Geophysics from the University of Wisconsin, an MS in Geology from The University of Texas at Austin, and a PhD in Geology from the Colorado School of Mines.

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Christi Gell develops and executes sales and growth strategy for DecisionSpace® Earth Modeling. She has also developed and commercialized multi-disciplinary workflow across product lines for Halliburton's Veristim℠ Service. Gell has worked in Houston and Kuala Lumpur as the geological and geophysical technologies lead for the Asia Pacific Region and also in Halliburton's Production Enhancement product line. She began her career as an exploration geologist at Marathon Oil Company before joining Landmark Graphics of Halliburton in 2000. She cofounded Halliburton's Young Professionals in Energy group and published an paper in 2008 on young professionals in the oil and gas industry, published by the Society of Petroleum Engineers. She is active in several industry organizations, including serving on the membership committee of the American Association of Petroleum Geologists. She holds an M.S. in Geology from the University of Houston and a B.S. in Geology from The University of Texas at Austin.

MINERAL RIGHTS AND LEASING

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Dan McCue is Director of Land Management for Calera Corporation of Los Gatos, California. Additionally, since 1995, McCue has been an instructor at the PETEX Houston Training Center teaching Aspects of Leasing and Joint Venture Partnerships, both onshore the United States and along the Outer Continental Shelf.

Prior to Calera, McCue served Spinnaker Exploration Company as Senior Landman. From 1998 to 2007, McCue was responsible for Spinnaker's lease acquisitions, negotiating commercial deals, drafting operating, farmout, and production handling agreements, and coordinating all competitor analysis for federal lease sales in both shelf and deepwater Gulf of Mexico.

Following the sale of Spinnaker Exploration to Norske Hydro, McCue joined newly formed Beryl Oil and Gas LP as Vice President of Land in 2007. There he was responsible for creating Beryl's Land Department for the integration of newly acquired Gulf of Mexico assets. In 2009, Beryl was sold to Dynamic Offshore Resources.

McCue has a B.B.A. in Petroleum Land Management from The University of Texas at Austin. He then spent 18 years with Amoco Production Company as a Senior Land Negotiator, assigned to various regions of the United States including Alaska.

In this chapter:

- The basic concepts of geology
- The origin of petroleum
- Types of rock and their formations
- The importance of porosity and permeability
- How reservoir pressure influences flow

1.1 Petroleum Geology

The science of geology deals with the origin, history, and physical structure of the Earth and its life, as recorded in rocks. An understanding of the basic principles of geology is essential to the petroleum industry, because most petroleum is found in underground formations made of rock.

Geologists try to answer such questions as: How old is the Earth? Where did the Earth come from? What is the Earth made of? And how has the Earth changed through time? Geologists study the evidence of events occurring millions of years ago, such as earthquakes, volcanoes, and drifting continents and relate these to similar events happening today. They look for evidence of the locations of ancient rivers, deltas, beaches, and oceans and try to decipher how these features shifted position with time. They also research the composition of rocks in the Earth's crust. In their intensive analysis of the Earth, geologists also draw on information from many other sciences, such as astronomy, chemistry, physics, and biology.

The petroleum geologist is primarily concerned with rocks that contain oil and gas, particularly rocks that contain enough petroleum to be commercially valuable. The company that drills for oil wants a reasonable chance of making a profit on its eventual sale, factoring in market price, the amount of recoverable petroleum, the expected production rate, and the cost of drilling and producing the well. Therefore, petroleum geologists actually have two jobs:

- They reconstruct the geologic history of an area to find likely locations for petroleum accumulations.
- They find one of these locations and evaluate it to determine whether it contains enough petroleum to be commercially productive.

Among the general population, there is a common misconception of oil reservoirs. Many people think that an oil reservoir is a large, subterranean cave filled with oil or a buried river flowing with crude oil from bank to bank. Nothing could be further from the truth. Yet it is easy to understand how such ideas come about. Even experienced oilfield workers often refer to a reservoir as an *oil pool*. And because many cities store their drinking water in ponds or lakes also called reservoirs, this term adds to the confusion. In reality, a *petroleum reservoir* is a rock formation that holds oil and gas, somewhat like a sponge holds water.

1.2 Petroleum Exploration

In this chapter:

- Collecting data using survey tools and databases
- The evolution of seismic surveys and interpretation
- Types of well logs and core samples
- Contour maps and digital computer models

In the past, exploring for petroleum was a matter of good luck and guesswork. Drilling near oil or natural gas seeps where hydrocarbons were present on the surface was the most successful hydrocarbon-finding method in the early days of oil exploration. Today, petroleum explorationists use sophisticated technologies and scientific principles and guidelines to find oil and gas. An *explorationist* is a person with extensive geological training whose job it is to search for new sources of hydrocarbons.

Surface and subsurface geological studies drive the discovery of oil and gas. Seismic data, well log data, aerial photographs, satellite images, gravity and magnetic data, and other geological data provide information that help determine where to drill an exploratory well. Specialists examine rock fragments and core samples brought up while drilling the exploratory well and run special tools into the hole to get more information about the formations underground. Examining, correlating, and interpreting this information make it possible for petroleum explorationists to accurately locate subsurface structures that might contain hydrocarbon accumulations worth exploiting.

SURFACE GEOGRAPHICAL STUDIES

In relatively unexplored areas, petroleum explorationists study the *topography*—the natural and manmade features on the surface of the land—to derive a conclusion about the character of underground formations and structures largely from what appears on the surface.

Aerial Photographs and Satellite Images

Before choosing a site to study, geologists might contend with an unexplored area covering tens of thousands of square miles or kilometres. To narrow this vast territory down to regions small enough for detailed surface and subsurface analyses, geologists might use a combination of aerial and satellite imaging. A series of landscape features that seem unrelated or insignificant to a ground observer might be interpreted quite differently when seen from the air or on a satellite image.

Previously, aerial photography was the only way to examine the land from the air. Aerial photography had some serious disadvantages.

1.3 Mineral Rights and Leasing

In this chapter:

- Ownership of mineral resources
- Leasing laws and procedures both onshore and offshore
- Private land rights in the United States
- Lease contract terms and provisions
- Executing a lease and managing agreements

Before a petroleum company can develop oil or gas *reserves*, it must acquire the legal rights to explore, drill, and produce on the site. Acquiring rights differs from country to country. In most oil-producing nations, mineral resources are owned by the national government and petroleum corporations must negotiate with government representatives to secure contracts for mineral development. The complexity, cost, and, in some cases, instability of these arrangements can be significant.

Governments worldwide frequently section their lands into smaller areas called *licenses*, or *leases*. Governments regularly offer licenses or leases to oil companies on certain terms so the companies may begin exploring, developing, and producing oil and gas located under the land. The terms and conditions of these licenses vary widely around the globe (fig. 1-3.1). When the licensing process is government-centered, it can be very bureaucratic and cause delays in parts of the process that can take years to resolve.

In most countries, governments or government rulers own all rights to minerals in the land or under waters (fig. 1-3.2). In other words, the state or national governments own all mineral rights including petroleum. Companies with the capital and expertise will negotiate contracts with representatives of the government. Frequently, the host country retains controlling interest throughout exploration and development. The agreements between a host country and the petroleum companies, many of which are also state or nationally owned, can be extremely complex.

For example, in the United Kingdom, the Queen has rights to extract minerals from all lands in the country, including those located offshore. This means that owners of surface land–whether land under a house or farmland–have no rights regarding mineral ownership.

Although much of the land and mineral wealth belong to state and federal governments in the United States, vast amounts of land—about two-thirds of U.S. onshore territory—belong to private individuals. This means that companies wanting to exploit domestic oil and gas reserves must acquire the rights to do so from private citizens. The legal instrument used to transfer these rights from both private and public ownership to a petroleum company is an *oil and gas lease*, which is another form of a license.

PART 2
Drilling

The Authors

DRILLING

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Fred Florence has over 30 years of industry experience including managing deepwater semisubmersibles, jackup rigs, and drillships for land, slim-hole, and helicopter operations. He currently leads a team to ensure machine controls are compatible with each other and with newly developed drilling models. Prior to joining NOV, Florence worked for Sedco-Forex, now Transocean, where he held various positions in engineering and operations. He is a member of the Society of Petroleum Engineers and serves on the steering committee of the new Drilling Systems Automation Technical Section formed to promote an industry-wide effort to develop and implement automation tools to improve drilling processes. He holds a B.S. in Electrical Engineering from Southern Methodist University, an M.A. in International Management, and an M.B.A. in Marketing from the University of Texas at Dallas.

MWD AND LWD

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John Rasmus specializes in Schlumberger's logging while drilling (LWD) product line. His current duties include field and client support of LWD interpretation, resistivity and nuclear interpretation support, and special projects. He has held various interpretation development positions, developing new and innovative interpretation techniques for secondary porosity in carbonates, geosteering of horizontal wells, geopressure quantification in undercompacted shales, and downhole motor optimization. Rasmus holds a B.S. in Mechanical Engineering from Iowa State University, and an M.S. in Petroleum Engineering from the University of Houston. He is a member of the Society of Petrophysicists and Well Log Analysts, Society of Petroleum Engineers, American Association of Petroleum Geologists. In addition, he is a registered professional petroleum engineer in Texas as well as a registered professional geoscientist.

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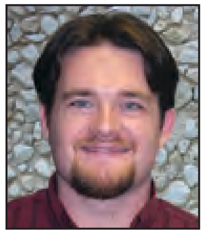
John Hadjioannou specializes in forensic engineering and failure analysis. As a mechanical engineer, Hadijoannou oversees laboratory activities for a broad range of testing, from metallurgical and mechanical testing to failure analysis and corrosion testing. His expertise covers micro and macro fractography to ascertain failure modes and corrosion mechanisms that cause failures of metals and coatings. He has key experience using engineering analyses, such as finite element analysis, to design products and parts when investigating failures. Hadjioannou holds a B.S.M.E. from Southern Methodist University and is a member of American Society of Mechanical Engineers, American Society of Metals International, and American Society for Testing and Materials International. Hadjioannou also serves as an instructor for the Petroleum Extension Service (PETEX) Houston Training Center where he teaches a course on pipeline mainline materials of construction.



Adam Cook
Mechanical Engineer,
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Adam Cook is a mechanical engineer trained in forensic engineering, finite element analysis and solid modeling for design and failure analysis. He has experience in the use of scanning electron microscope to evaluate fracture morphologies. At EPI, Cook provides support to principle engineers in forensic and metallurgical projects. Prior to his current position, he served as a certified Operations Engineer for Mission Control Emergency Power Plant at National Aeronautic Space Administration Johnson Space Center. He holds a B.S. in Mechanical Engineering from the University of Kentucky and is a member of the American Society of Mechanical Engineers, the American Society of Materials, and the American Institute of Aeronautics and Astronautics.

CONTROLLED DIRECTIONAL DRILLING

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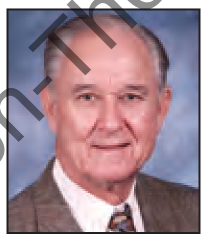
João Luiz Vieira is responsible for introducing and marketing performance-drilling technology, including promoting a new vertical drilling tool, V-Pilot, and the mud motor-powered rotary steerable Geo-Pilot GXT. He managed directional drilling efforts for 18 years in northeast Brazil and in the Campos Basin in Macae. Vieira came to Houston in 2005 as Business Development Manager for the Latin America Region in charge of introducing new technologies in the region. He has an M.S. in Mechanical Engineering from the Universidade Federal do Espirito Santo and received training at Petrobras Corporate University in Salvadorl. He authored the book, Controlled Directional Drilling, 2nd edition, published by PETEX, and has coauthored a book on directional drilling in Brazil. In addition, Vieira has contributed to numerous papers and articles on directional drilling technologies and is a seasoned instructor, delivering classes on directional drilling to corporate personnel worldwide.

MUD DENSITY



Bill Rehm

Independent Drilling Consultant
Far East Energy

Bill Rehm's expertise focuses on issues surrounding well pressure and improving safety in drilling well control. He began his career at Dresser Industries developing well control and pressure measurement from electric logs. He wrote the first manual on well control accepted by the U.S. Minerals Management Service, and throughout his career, has contributed to some of the most significant technological advancements in recent history including the development of directional drilling, coiled tubing, underbalanced drilling, and high-pressure drilling operations. Rehm was honored in 2009 as recipient of the Legends in Drilling Award presented by the Journal of Petroleum Technology. He has authored several books, including Practical Underbalanced Drilling and Workover, published by PETEX, and has contributed content to other PETEX drilling publications. He is a current member of the PETEX Advisory Board.

SAGD

Jerry Haston

Drilling Engineer
Independent Drilling Consultant

Jerry Haston has more than 35 years of experience in all aspects of drilling and completion activities including mud engineering, drilling engineering, training, well control, supervision, and management in the United States and globally. In 1977, Haston started his consulting business, providing well-site supervision, preparing well plans, and writing and teaching training courses. He began his career with Seis-Tech Exploration and was assigned to Alaska. He then worked as a mud logger for drilling operations in south Texas before joining Sun Oil Company as a geologist locating new drill sites in west Texas. Haston later became a field engineer for Dresser Industries serving Magcobar in the U.S. Rocky Mountains. His roles grew to include management, operations, training, and technical writing. He has a B.S. in Geology from the University of Oklahoma and is an active member of the Society of Petroleum Engineers. Haston also teaches classes on drilling technology for PETEX at its Houston Training Center and for PETEX programs at client sites.

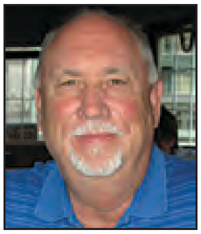
FISHING

Dale Arceneaux

Fishing Tool
Senior Tech Representative
Energy Fishing and Rental Services

Dale Arceneaux has over 45 years of experience working in the oil industry specializing in fishing and downhole intervention. He has held key positions at Tri-State Oil Tools, Wilson Downhole, Petro-Hamco-Enterra/Weatherford, QTS Fishing and Rental, Deltide Fishing and Rental, and Key Energy. He instructs classes on fishing technologies for PETEX at the Houston Training Center.

WELL CONTROL



Steve Vorenkamp

Training Director
Wild Well Control, Inc.

Vorenkamp has 35 years of oil industry experience specializing in pressure detection and target drilling. He currently directs training for Wild Well Control, Inc., a well-established, globally recognized well control company whose training division operates schools for the International Association of Drilling Contractors and the American Petroleum Institute. Vorenkamp's extensive background includes previous positions serving as Manager of WCS Houston for Cudd Pressure Control, President and COO of The Superior Logging Company, Inc.; owner of VOSCON Inc., a directional consulting company, and the Dallas District Manager for Schlumberger. He holds a B.A. in Business Management from Tulane University at New Orleans and a B.S. in Earth Science from the University of New Orleans. Vorenkamp also instructs classes on well control for PETEX at the Houston Training Center and is a member of the PETEX Advisory Board.

DRILLING SAFETY

Jim Johnstone

President and Co-founder
Contek Solutions LLC

Jim Johnstone, a 30-year veteran of the oil and gas business, has worked with various companies to implement management systems and set up exemplary safety programs. He has led process hazard reviews, implemented behavioral-based training programs, conducted safety training, led safety compliance initiatives and investigated incidents. Johnstone began his career with ARCO (now BP) and later became responsible for all its process safety and support of environmental health and safety regulatory compliance for worldwide operations. He has participated in numerous technical committees and authored technical content, including safety publications for the American Petroleum Institute. He holds a B.S. in Mechanical Engineering from Washington State University and a Certified Safety Professional certificate from the Board of Certified Safety Professionals. Johnstone is a member of the Society of Petroleum Engineers, American Society of Safety Engineers, and American Society of Mechanical Engineers.

2.1 Drilling Operations

In this chapter:

- Early drilling methods and operations
- Drilling contracts and drilling personnel
- Rotary drilling systems
- Routine drilling operations
- New drilling technologies
- Offshore drilling units and special operations
- Uses, tools, and techniques of directional drilling
- Fishing, retrieving, and repairing pipe
- Unconventional drilling methods

Once the exploration geologists and geophysicists have obtained and analyzed data for the prospective site, the landman has secured a lease, and drilling permits and other preliminary papers are in order, the company turns its attention to drilling. To understand the complex science and art of drilling for oil and gas, it is important to take a look back at the history of drilling for oil, beginning at the start of the Industrial Revolution.

A NEW ERA IN ENERGY

In the 1800s, workers wanted a better way to illuminate their homes when they returned from labor in factories. In response to this demand, companies began making oil lamps that burned sperm whale oil, which provided a clean, nearly odorless flame that emitted bright light. Unfortunately, the high demand for whale oil resulted in scarcity and near extinction of the whales sacrificed to produce it. Whale oil became so costly that only the wealthy could afford it. An affordable and plentiful replacement for whale oil became necessary. At the same time, factories also demanded reliable lighting as well as good quality lubricants to run steam-powered machines to keep industry churning. Fortunately, an oily substance was noticed seeping from the ground at locations around the world, and the energy landscape changed.

2.2 Well Control

In this chapter:

- Definition of well control
- Crewmember roles in controlling a well
- Significance of wellbore pressure
- Process of shutting in a well
- Early detection signs and warnings

Well control has been a critical component of operational awareness in oilfields for as long as wells have been drilled. A common example of a well that is out of control is Colonel Drake's historic well in Titusville, Pennsylvania, drilled in 1859. The explosion of oil at the surface of this well is classified as an *unscheduled event*. Today, such events are relatively rare and can be prevented due to proper planning, training, and communication.

AN OUT-OF-CONTROL WELL

A well is out of control when reservoir gas or fluids are flowing in a way that cannot be regulated or stopped. A well in an *underbalanced* condition can cause an unrecognized influx of either gas or fluids—or both—that has reached critical limits, beyond what normal operations can handle or contain (see section on The Use of Mud Density in *Part 2, Chapter 2.1: Drilling Operations*). This type of situation can cause a dramatic release to the surface, called a *blowout*, and present serious dangers to workers and resources (fig. 2-2.1).

Figure 2-2.1. A blowout and resulting fire at Greenhill Well in Timbalier Bay, Louisiana

Source: National Oceanic and Atmospheric Administration (NOAA)

2.3 Drilling Safety

In this chapter:

- Common drilling hazards
- Preparing the site for drilling
- Risks associated with drilling operations
- Safety as the highest priority

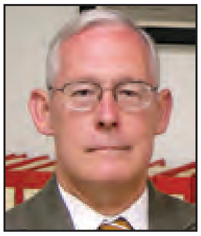
Drilling rigs contain many hazards (fig. 2-3.1). The very nature of rotating machinery—engines, pumps, drawworks—and electrical equipment, confined spaces, chemicals, elevated work surfaces, and extreme noise creates serious hazards for workers. Of particular concern is the high pressure associated with circulating drilling mud. Workers must always be on guard for changing situations, particularly those that might lead to a blowout (discussed in *Chapter 2.2. Well Control*). Offshore rigs present additional hazards due to the harsh and remote aspects of deepwater marine environments.

Figure 2-3.1. Drilling rigs present potential hazards for all workers on site. Every worker must be thoroughly trained in the specific skills and requirements of their job to ensure safe operations.

PART 3
Production

The Authors

PRODUCTION PRACTICES



Paul Bommer

Senior Lecturer, Petroleum and Geosystems Engineering
The University of Texas at Austin

Paul Bommer, university instructor and co-owner of Bommer Engineering Company, has spent over 25 years in industry as an oil and gas operator and consultant in Texas and other parts of the United States. A third-generation oil man, Bommer joined the faculty of The University of Texas at Austin in 2004 and teaches courses in drilling, production, artificial lift, and facilities. His many years in private practice involved specializing in drilling and production operations and oil and gas appraisals. Bommer has published articles on solution mining, beam pump design, and well log analysis. He is the author of the best-selling book, Primer of Oilwell Drilling, 7th edition, published by PETEX. He has served as an instructor in petroleum-related courses at The University of Texas at Austin, the University of Houston at Victoria, and at Bee County Community College. Bommer is a Registered Professional Engineer in the State of Texas, a member of the Society of Petroleum Engineers and the American Petroleum Institute, and a member of the PETEX Advisory Board. He received his B.S., M.S., and Ph.D. degrees in Petroleum Engineering, all from The University of Texas at Austin.

PRODUCTION SAFETY

Jim Johnstone

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Jim Johnstone, a 30-year veteran of the oil and gas business, has worked with various companies to implement management systems and set up exemplary safety programs. He has led process hazard reviews, implemented behavioral-based training programs, conducted safety training, led safety compliance initiatives and investigated incidents. Johnstone began his career with ARCO (now BP) and later became responsible for all its process safety and support of environmental health and safety regulatory compliance for worldwide operations. He has participated in numerous technical committees and authored technical content, including safety publications for the American Petroleum Institute. He holds a B.S. in Mechanical Engineering from Washington State University and a Certified Safety Professional certificate from the Board of Certified Safety Professionals. Johnstone is a member of the Society of Petroleum Engineers, American Society of Safety Engineers, and American Society of Mechanical Engineers.

3.1 Production Practices

In this chapter:

- Completing the well for production to begin
- Wellhead equipment that controls fluid flow
- Fluid pressure and initiating flow
- Artificial methods of lifting fluids
- Mechanisms that drive fluids from the reservoir
- Methods of handling well fluids on the surface
- Well servicing and workover operations

In the petroleum industry, *production* is the phase of operation that deals with bringing well fluids to the surface and preparing them for transport to the refinery or processing plant. Production begins after drilling is finished and the *borehole* is carefully evaluated and determined to be economically productive. On the other hand, a borehole judged to be economically unproductive is plugged and abandoned.

Production is a combination of these operations:

- Preparing the borehole for production
- Bringing fluids to the surface
- Separating into oil, gas, and water streams that are measured for quantity and quality

For boreholes drilled to economically productive reservoirs, the first step is to *complete* the well—that is, to perform operations necessary to start the well fluids flowing to the surface. Routine maintenance operations are expected. *Servicing* such as replacing worn or malfunctioning equipment is standard during the well's producing life. Later, more extensive repairs, known as *workovers*, might be necessary to maintain the flow of oil and gas.

Well fluids, usually a mixture of oil, gas, and water, must be separated when they reach the surface. Water must be disposed of and equipment installed to treat, measure, and test the oil and gas before transporting them from the well site.

Detailed discussions on these concepts follow in this order: completion, fluid flow, reservoir drive mechanisms, improved recovery, surface handling, well servicing, and remote production environments.

3.2 Remote Production

In this chapter:

- Producing wells offshore
- Completing wells in deep waters
- Special fluid-handling requirements
- Submerged production systems
- Permafrost considerations

Hydrocarbons produced from offshore and Arctic wells require the same general types of completions and surface separation and handling as land wells. The main differences are due to the remoteness of the locations and the special challenges of the environments.

OFFSHORE PRODUCTION PLATFORMS

If the ocean water depth is shallow enough to allow construction of a drilling platform, and if one or more development wells are drilled and production takes over as the main activity then the drilling platform will also become a production platform (fig. 3-2.1). The operator sometimes removes the drilling rig or allows it to remain on the platform to service the producing wells. Some platforms are designed so that a mobile offshore jackup drilling rig can set up over the platform to drill and complete a well through the platform or through a single well caisson (fig. 3-2.2)

Courtesy of Hibernia Management and Development Company Ltd.

Figure. 3-2.1. This self-contained platform, the Hibernia, houses all the drilling and production equipment and facilities for the crew. The Hibernia is located off the coast of Newfoundland and is the world's largest oil platform in terms of weight.

3.3 Production Safety

In this chapter:

- Safety in all aspects of the production process
- Hazards that commonly occur in production
- Factors in monitoring process conditions
- Common production hazards

Production safety encompasses a wide variety of jobs and functions spanning from when the well is first brought into production to when the well is abandoned and the facilities are removed. Production workers need to understand how to work safely when conducting various jobs on a production site (fig. 3-3.1). During the course of each day, production workers are frequently called upon to drive to a well site or production facility, diagnose equipment or well problems, make repairs to wells and equipment, adjust process settings, and ensure that safety equipment is working properly. Each task has its own inherent safety hazards and particular safety requirements.

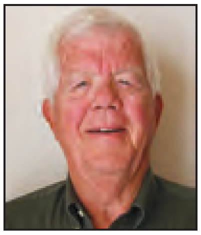
Figure 3-3.1. Production worker controlling flow of fluids with valve

PART 4

Transportation and Refining

The Authors

TRANSPORTATION/ PIPELINES



Larry Bennington
Owner and Pipeline Consultant
Milepost Consulting

Larry Bennington has over 35 years of experience dealing with all aspects of pipelining. He currently provides consulting services to the pipeline and related industries in areas of operations, maintenance, engineering, construction, planning, regulatory compliance and litigation support. His expertise includes pipeline operations, maintenance, planning, project engineering, technical services, and engineering services including construction management, right-of-way, and records management. He has held key positions at Amoco Pipeline Company and American Oil Company and is a Registered Professional Engineer. Bennington holds a B.S.C.E. in Civil Engineering and an M.B.A. from Kansas State University. He is a current pipeline instructor at the PETEX Houston Training Center and for special PETEX programs at client locations.

LIQUEFIED NATURAL GAS

Stanley Huang
LNG Process Engineer
Chevron Corporation

Stanley Huang specializes in cryogenic applications, particularly in liquefied natural gas and gas processing. For nearly 15 years, he has worked on numerous projects devoted to LNG baseload plants and receiving terminals and has contributed to process and technology improvements through more than 20 publications and corporate reports. Before joining Chevron, Huang worked for IPSI (an affiliate of Bechtel) and KBR. He began his career with Exxon Research and Engineering Company and later joined D.B. Robinson and Associates in Canada. An expert in thermodynamics, Huang has given seminars on thermodynamic applications and, in recent years, has presented on gas processing and the LNG industry at meetings of the Association of Chinese American Professionals and at the Universities of Houston and Wyoming. He also instructs classes on LNG processes at the PETEX Houston Training Center. Huang received a B.S. from National Taiwan University and an M.S. and a Ph.D. in Chemical Engineering and an M.S. in Physics from Purdue University.

REFINING AND GAS PROCESSING

Stephen Long
Technology Advisor
Valero Energy Corporation

Stephen Long has 35 years of experience in the refining and petrochemical industry working in operating, engineering, and consulting companies and as an independent contractor. He is currently Technology Advisor in Strategic Sourcing for Valero Energy Corporation in San Antonio, Texas.

Prior to Valero, Long served the refining and petrochemical industry as an independent consultant associated with several company expansion projects. He spent 18 years devoted to the operating side of the industry as a refinery process engineer, plant process engineer, technical manager, operations manager, and refinery manager. His operations experience included virtually all types of refinery units.

Long's background includes several years with Stone and Webster focused on technology and process activities. In 2001, Long became President and Director of Energy Management Corporation in Houston, Texas, providing operations and maintenance services for a small niche refinery overseas. He served as General Director and an owner of Azov Oil Company from 2002 to 2004.

4.1 Transportation

In this chapter:

- Transportation in the early days
- Ground modes of transport
- Marine transportation for oil and natural gas
- Pipeline infrastructure and operations
- Liquefied natural gas shipping and offloading

Transporting and distributing petroleum products and natural gas from oilfields to refining and processing plants requires a complex transportation system (fig. 4-1.1). Tank trucks, rail cars, marine transportation, and crude oil, products, and gas transmission pipelines each have an important role in the oil and gas transportation industry.

Crude oil was first transported in wooden barrels carried by horse-drawn wagons to nearby streams. As consumer demand for petroleum grew, so did the methods of transportation. Today, millions of barrels of crude oil, gasoline, fuel oils, and other petroleum products, along with billions of cubic feet of natural gas, are moved daily from the wellhead to refineries. They are also moved from refineries to product terminals, from one refinery to another, from offshore to onshore, and from continent to continent to reach consumers.

Photo by Mark Toigo. Courtesy of www.seefloridago.com

Figure 4-1.1. The transportation industry is responsible for moving millions of barrels of crude oil daily across land and water to reach processing facilities and consumers.

In this chapter:

- Structure of hydrocarbons in oil and gas
- Distillation and cracking processes
- Hydrotreating and blending fuels
- Petrochemical plant and processes
- Product marketing, sales, and distribution

4.2 Refining and Processing

Collected crude oil and natural gas are of little use in their raw state. Their value lies in what is created from them—fuels, lubricating oils, waxes, asphalt, and petrochemicals.

To passersby, crude oil refineries and natural gas plants look like a strange conglomeration of towers and walls and a maze of pipes and tanks (fig. 4-2.1). In reality, a refinery is an organized and coordinated arrangement of equipment that separates the components in crude oil and gas and produces physical and chemical changes in them. These changes create salable products of the quality and quantity consumers want. Crude oil refineries and natural gas plants also include facilities to store crude oil and products and maintain equipment.

Courtesy of Valero Corporation

Figure 4-2.1. A refinery is an organized and coordinated arrangement of processes (called units) linked together with miles of pipe carrying crude oil in and products out. Pictured: Valero Corporation's Jean Gaulin Refinery in Quebec, Canada, has a capacity of 215,000 barrels per day.

4.3 Gas Processing

In this chapter:

- Functions of gas processing plants
- Natural gas liquids and cryogenic recovery
- Absorption and adsorption processes
- Fractionation to produce salable products

As late as the 1930s, natural gas leaving the wellhead had to reach a market nearby or else be burned off, or *flared*. Huge amounts of natural gas have been flared in the United States. Flaring is still a common practice in remotely located oilfields when gas cannot be reinjected into the reservoir for gas lift or used locally as fuel. With the advent of gas pipelines (commonly called *transmission lines*), gas transport trucks, and field processing facilities for gas, gas production in the United States and elsewhere has become an industry in itself.

Natural gas straight from the well is processed in the field. The processing includes the removal of water, impurities, and excess hydrocarbon liquids as required by the sales contract. It also includes the control of delivery pressure. When it is economical to gather the gas from several wells to a central point, an operator may build a gas processing plant to do the same work as separate facilities next to each well would do. Often, these gas plants dehydrate the gas and remove hydrogen sulfide. In addition, they generally separate hydrocarbon mixtures or individual hydrocarbons from natural gas and recover sulfur and carbon dioxide.

In general, the larger the gas processing plant, the more economical it is to operate (fig. 4-3.1). However, large plants must be near fields that provide large volumes of natural gas. In recent years, manufacturers have developed portable skid-mounted plants to provide efficient, relatively inexpensive gas processing for smaller fields.

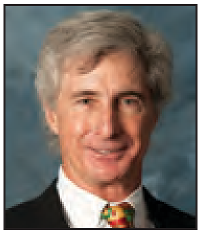
In addition, refineries have facilities to process the gases resulting from crude oil distillation, cracking, and reforming. Refinery gas processing provides fuel gas (methane, ethane, and ethylene) to power refinery operations. Refineries also separate individual natural gas liquids (NGLs), which may be used to make fuel products or may be sent to an alkylation unit for further processing.

PART 5

The Changing Market

The Authors

ECONOMICS



Rick Bobigian

President and Chief Executive
Black Pool Energy

Rick Bobigian is President and Chief Executive of Black Pool Energy GP LLC, the general partner of Black Pool Energy LP. He is also a founder and member of its Board of Managers. Prior to Black Pool, Bobigian managed business functions for Osprey Petroleum Company, a firm engaged in the search for oil and gas offshore along the Texas Shelf. He was a founder, Executive Vice President, and member of the Board of Directors of Osprey. Before Osprey Petroleum, Bobigian engaged in the oil and gas business using various special-purpose entities to invest in both upstream and midstream assets. He is Chair of the PETEX Advisory Board and a long-time instructor of petroleum economics for PETEX at the Houston Training Center. Bobigian earned a B.S. in Geologic Engineering from the Colorado School of Mines.

ENVIRONMENTAL CONCERNS

Joe Ibanez

Chief Executive Officer
SAGE Environmental Consulting

Joe Ibanez has nearly 15 years of experience in the environmental field. He is currently a partner and key principal at Sage Environmental Consulting, LP. His broad experience covers hazardous waste and water issues, focusing on Clean Air Act regulations. Ibanez has worked extensively with all sectors of the oil and gas industry in preparing and negotiating complex permitting projects. He has completed environmental audits and helped multiple facilities implement environmental management systems. This experience has enabled him to directly interface with industry and local, state, and federal agencies (such as the Texas Commission on Environmental Quality and EPA Region 6) to solve technical and regulatory problems.

Along with participating in technical reviews and regulatory negotiations on projects, Ibanez participates in providing leadership and strategic planning for Sage and helped develop and implement a company-wide performance measurement system focused on generating and managing sustainable growth. Ibanez has a Chemical Engineering degree from The University of Texas at Austin.

ENERGY OPTIONS

Michael Webber

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The University of Texas at Austin

Michael Webber is Associate Director of the Center for International Energy and Environmental Policy, Co-Director of the Clean Energy Incubator, and Assistant Professor of Mechanical Engineering at The University of Texas at Austin. He is on the Board of Advisors of Scientific American and has authored more than 125 articles, columns, and book chapters. He has given more than 150 lectures, speeches, and invited talks in the last few years, including testimony for a U.S. Senate hearing, keynotes for scientific conferences, and lectures at the United Nations. Michael holds four patents and is an originator of the Pecan Street Project, a multi-institutional public-private partnership in Austin to create the smart electricity and water utilities of the future. He earned B.A. and B.S. degrees in Liberal Arts and Aerospace Engineering from UT-Austin and a M.S. and Ph.D. degrees in Mechanical Engineering from Stanford University.

INDUSTRY SAFETY

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Contek Solutions

Jim Johnstone, a 30-year veteran of the oil and gas business, has worked with various companies to implement management systems and set up exemplary safety programs. He has led process hazard reviews, implemented behavioral-based training programs, conducted safety training, led safety compliance initiatives and investigated incidents. Johnstone began his career with ARCO (now BP) and later became responsible for all its process safety and support of environmental health and safety regulatory compliance for worldwide operations. He has participated in numerous technical committees and authored technical content, including safety publications for the American Petroleum Institute. He holds a B.S. in Mechanical Engineering from Washington State University and a Certified Safety Professional certificate from the Board of Certified Safety Professionals. Johnstone is a member of the Society of Petroleum Engineers, American Society of Safety Engineers, and American Society of Mechanical Engineers.

5.1 Petroleum Economics

In this chapter:

- Supply chain businesses that create new supplies of oil and gas
- Supply creation companies and how they operate
- Factors in investment decision-making
- Calculating rates of return to evaluate prospects
- Predicting future commodity prices

Conventional supplies of crude oil and natural gas are, by definition, extracted from reservoirs in the sedimentary rocks by means of wells drilled and equipped to flow or lift raw materials to the surface. Upon reaching the surface, these raw materials are partially processed at the well site to remove contaminates such as saltwater and poisonous and inert gases and solids. Next, these partially processed raw materials are transported from the well site via pipeline, barge, ship, or truck to a refiner for crude oil or a natural gas processing facility for natural gas (figs. 5-1.1 and 5-1.2). These raw materials are converted into finished and semi-finished products to be sold and consumed.

Figure 5-1.1. Crude oil refinery

5.2 Environmental, Health, and Safety Concerns

In this chapter:

- Laws and regulations to protect human health and the environment
- Exploration and production waste disposal
- Cleanup methods for blowouts and spills
- Refining processes that minimize environmental impact
- Equipment and controls to promote workplace safety

Petroleum products are everywhere. Many of the common household items we use every day contain petroleum. Unfortunately, the recovery, transport, processing, and use of petroleum are fraught with potential hazards to human health and the Earth's ecology. For example, exploration, drilling, and production use toxic chemicals that can pollute the air, water, and ground to yield a product that might be very useful but is also poisonous to most living things. Producing and transporting petroleum products pose risks of fire, explosions, and pollution. Similarly, refining it produces still more noxious chemicals that must be changed into harmless compounds or disposed of in harmless ways (fig. 5-2.1).

For these reasons and because of its size and importance to the economy, the petroleum industry is subject to much criticism. Various environmental groups monitor the industry and publicize dangers and potential dangers they find or suspect. Oil companies face a great public relations challenge in regard to their adverse impact to the environment.

Figure 5-2.1. Recovery, transport, processing, and use of petroleum have potential hazards to human health and the Earth's ecology.

5.3 Energy Options and Policy

In this chapter:

- Petroleum and other energy sources
- Challenges and priorities
- Critical technologies of the future
- Nontechnical solutions

Petroleum is only one source of energy. People and countries care about energy because it is relevant to many sectors across societies. Many sources are used to supply that energy. The world uses a mix of oil, coal, natural gas, nuclear, and other alternatives, in order of decreasing magnitude. The world's use of fuels includes slightly less oil and slightly more traditional *biomass*, such as wood or cow dung, than the United States, but other than that has a similar mix. In the United States, petroleum is the leading fuel source, followed by natural gas, coal, nuclear, hydropower, and other renewable energy (fig. 5-3.1).

A *British thermal unit (Btu)* is equal to the energy of about one standard kitchen match. In 2004, the United States reportedly used one billion million Btus a year. A *quad* is 1 quadrillion Btus, or 1×10^{15} Btus. In 2004 alone, total energy use was approximately 445 quad for the world's consumption and 100 quad for consumption in the United States. Since then, global consumption has increased to approximately 500 quad in 2008, while consumption in the United States has stayed about the same.

The information presented in this chapter reflects the viewpoints of the author and is based on his extensive research and professional experience.

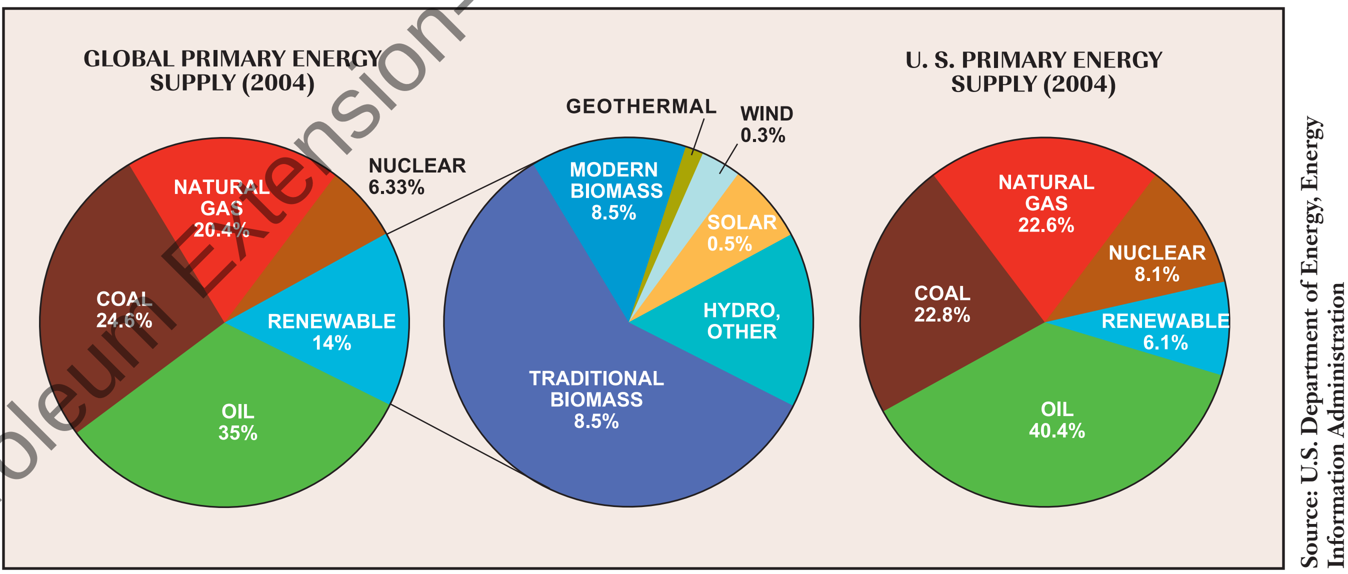

Figure 5-3.1. The global (left and middle) and United States (right) energy mix is diverse, although fossil fuels satisfy more than 80% of the world's primary energy resources.

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