COLORADO
DEPARTMENT OF NATURAL RESOURCES

ROCKTALK

Division of Minerals and Geology
Colorado Geological Survey

Volume 7, Number 2 April 2004

COLORADO HISTORICAL SOCIETY

OIL ...BLACK GOLD.. WHAT'S ALL THE FUSS ABOUT?

Oil, petroleum, hydrocarbon — words that have become popular in our modern-day vernacular, but what do they really mean to us? What is oil? How does it form? Where do we find it? How do we look for it? Do we really need it? Why? Are we actually running out? Does its use damage our environment? These are all good questions, but some of the answers are not quite so simple. This issue of *RockTalk* provides insights into the issues raised by these questions, and hopefully a better understanding of the industry that supplies so much of our energy needs.

What Is Oil?

Fossil fuels are those energy sources that formed from the remains of once-living organisms. They include oil, natural gas, coal, and fuels derived from oil shale and tar sand. *(See article on Oil Shale on page 13.)* The differences in the physical properties among the various fossil fuels arise from differences between the starting materials from which the fuels formed and changes to those materials after the organisms died and were buried within the layers of the earth.

Petroleum means rock-oil, and comes from the Latin *petra*, meaning rock or stone, and *oleum*, meaning oil. Liquid petroleum, or oil, comprises a variety of liquid hydrocarbon compounds; compounds made up of different proportions of the elements carbon and hydrogen. There are also gaseous hydrocarbons (natural gas), in which methane is the most common component. Hydrocarbon mixtures usually also contain

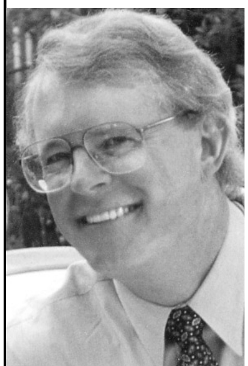
New Executive Director Named for the Department of Natural Resources

On January 8, 2004 Colorado Governor Bill Owens named Russell George as the new Executive Director for the Colorado Department of Natural Resources. He is charged with protecting and enhancing Colorado's natural resources. Specifically, Russ oversees the operations of the DNR's eight agencies, which include: the Colorado Division of Wildlife; the Colorado Oil and Gas Conservation Commission; State Parks; the Colorado Water Conservation Board; the Division of Water Resources; the Division of Minerals and Geology; the State Land Board; and the Division of Forestry. Prior to his current position, Russ served as Director of the Colorado Division of Wildlife.

In 1999, he was elected by his peers as Speaker of the Colorado House of Representatives, where he had served for eight years. As a House member, Russ served on the Judiciary, the Agriculture and Natural Resources, the Local Government and the Capital Development Committies.

Russ is a graduate of Rifle High School; Colorado State University, where he was a Boettcher Scholar; and Harvard University Law School. He co-founded the Stuver & George, P.C. law firm in Rifle, Colo., which has handled water, real estate, oil and gas, business and other legal matters since 1976.

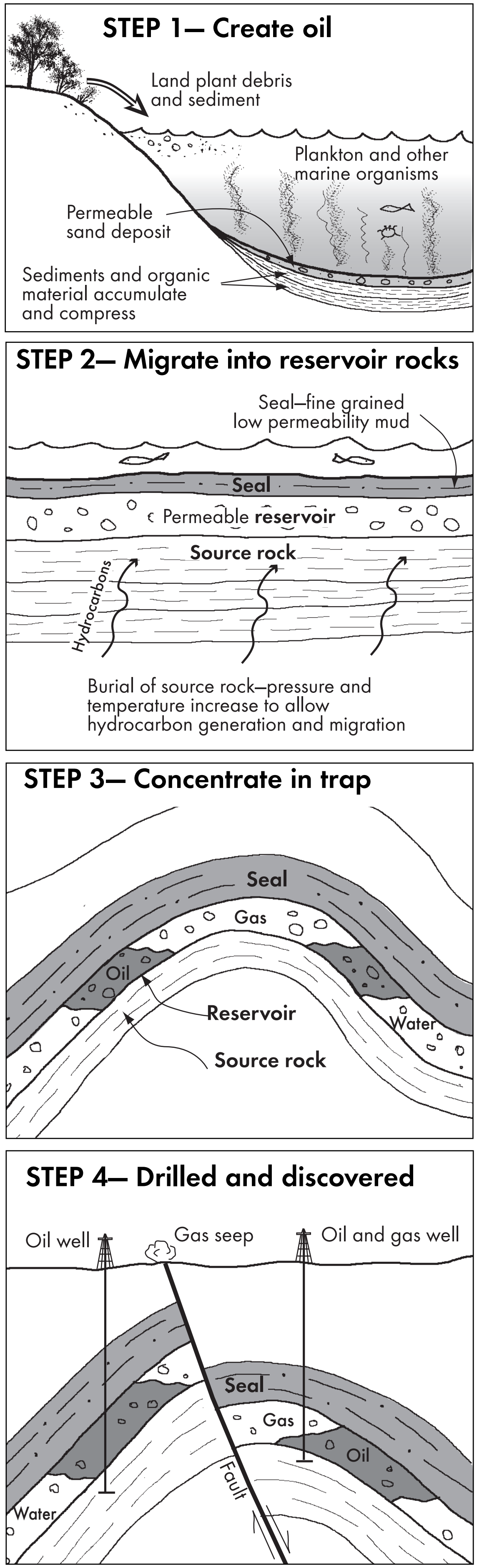
From the State Geologist



As I embark on the honor of serving as the third leader of the second, or "modern," Colorado Geological Survey, I reflect on my predecessors' shoulders upon which I stand, John Rold and Vicki Cowart, former State Geologists. Through their efforts we have a strong, competent, and committed group of people who are admired throughout the earth science profession, both within the state and nationally. The people of Colorado owe them both a debt of gratitude for their contributions toward protecting the health and safety of our citizenry and for promoting the responsible development of our state's vast natural resources. I personally thank them both for creating this great foundation on which to build. I also want to thank Ron Cattany for the many contributions he made to the CGS while serving as interim State Geologist for the past year.

Because this issue of *RockTalk* focuses on oil, I also think back on Burt Langredge, Colorado's Territorial Geologist in 1904–1906. He served at a time when there was not a clear wall between government service and private gain. Indeed, during the Boulder oil boom (which you can read about elsewhere in this issue), he raised $500,000 in order to participate in the drilling for the riches underly-

from the State Geologist cont. on p. 7



The creation of an economic accumulation of oil involves a long complex process.

Step 1. *Oil must be created in* ***source*** *rocks.*

Step 2. *Oil must migrate from source rocks to reservoir rocks that are capped by a* ***seal*** *rock.*

Step 3. *Oil must be concentrated in economic quantities by geological* ***traps*** *such as folds.*

Step 4. *Oil traps must be discovered by drilling.*

minor amounts of nitrogen, oxygen, and sulfur as impurities.

How Does It Form?

The production of a large deposit of any fossil fuel requires an even larger initial accumulation of organic matter, which is rich in carbon and hydrogen. Another requirement is that the organic debris be buried quickly to protect it from the air so that decay by biological activity or reaction with oxygen will not destroy it.

Microscopic life is abundant over most of the earth's oceans. When these organisms die, their remains can settle to the sea floor. There are also underwater areas near shorelines, such as on many continental shelves, where sediments derived from continental erosion accumulate rapidly. In such a setting, the starting requirements for the formation of oil are satisfied; there is an abundance of organic matter rapidly buried by sediment. Oil and most natural gas are believed to form from such accumulated marine microorganisms. Some natural gas deposits that are not associated with oil may form from deposits of plant material buried in sediment.

As burial continues, the organic matter begins to change. Pressures increase with the weight of the overlying sediment or rock; temperatures increase with depth in the earth; and slowly, over long periods of time, chemical reactions take place. These reactions break down the large, complex organic molecules into simpler, smaller hydrocarbon molecules. In the early stages of petroleum formation, the deposit may consist mainly of larger (heavy) hydrocarbons, which have the thick, nearly solid consistency of asphalt. As the petroleum matures, and as the breakdown of large molecules continues, successively "lighter" hydrocarbons are produced. Thick liquids give way to thinner ones, from which lubricating oils, heating oils, and gasoline are derived. In the final stages, most or all of the petroleum is broken down further into very simple, light, gaseous molecules—natural gas. Most of the maturation (cooking) process occurs in the temperature range of 50° to 100° C (approximately 120° to 210° F). Above these temperatures, the remaining hydrocarbon is almost entirely methane (natural gas); with further temperature increases, methane can also be broken down and destroyed.

Where Do We Find It?

Once the solid organic matter is converted to liquids and/or gases, the hydrocarbons need to migrate out of the **source** rocks in which they formed in order to form a commercial deposit. The majority of petroleum source rocks are fine-grained sedimentary rocks (like shale), from which it would be difficult to extract large quantities of oil or gas quickly. However, oil and gas are able to migrate out of their source rocks into more permeable rocks over the long spans of geologic time. Most people have the incorrect notion that there are underground "lakes" of oil. The oil industry has helped feed this misconception by talking about oil "pools." The truth is that virtually all the oil is contained in tiny holes in solid rock. These holes, or pores, are filled with water, gas, or oil. But if the holes are not connected, then oil can't flow out of the rock. The ability of liquid to flow through the pores is permeability. So, in addition to high porosity, which allows the rock to hold large amounts of oil, the rock must have good permeability, which allows oil to flow quickly out of the rock. A rock with good porosity and permeability is a **reservoir** rock. Most

NEW STATE GEOLOGIST APPOINTED

On March 9, Dr. Vincent Matthews was appointed Colorado's third State Geologist since the Colorado Geological Survey was reactivated in 1967. In his previous position as Senior Science Advisor, Matthews was responsible for CGS's geologic mapping, earthquake hazards research, and outreach programs. A native of east Tennessee, he received B.S. and M.S. degrees in Geology from the University of Georgia and a Ph.D. from the University of California, Santa Cruz.

Before joining the CGS in 2000, Vince spent over 20 years in the petroleum industry, working for four public companies. Additionally, he taught at the University of California, University of Northern Colorado, Arizona State University, the Frank Lloyd Wright School of Architecture, and the University of Texas of the Permian Basin.

> "It has been an honor for me to work with Vince over the past several years. I depend on his breadth of knowledge on geological issues as we work with our various constituencies on issues of statewide importance."
> —*Ron Cattany, Director of the Division of Minerals and Geology*

Matthews has conducted research and published articles on the San Andreas fault, global tectonics, subduction zone tectonics, igneous and metamorphic petrology, and Laramide deformation. He is the author of more than 50 technical articles and abstracts.

Vince is a Fellow in the Geological Society of America, a Trustee Associate for the American Association of Petroleum Geologists, has been an officer in the Rocky Mountain Association of Geologists, and is President-Elect of the Colorado Scientific Society. He has been on the Board of Directors of many industry organizations.

> "It is my pleasure to congratulate Dr. Vince Matthews on his appointment as Colorado State Geologist. Vince brings to the table over twenty years of experience in his field—his credentials are unmatched. He has served the Colorado Geological Survey well for the past four years, and he will continue to do so in his new position." – *Russell George*

oils and all natural gases are less dense than water, so they tend to rise as well as to migrate laterally through the water-filled pores of permeable rocks.

Unless sealed by impermeable **cap** rocks, oil and gas may keep rising right up to the earth's surface. These substances escape into the air, the oceans, or they flow out onto the ground at oil and gas seeps. These natural seeps, which are one of nature's own pollution sources, are not very efficient sources of hydrocarbons for fuel compared with present-day extraction methods.

Commercially, the most valuable deposits are those in which a large quantity of oil and/or gas is concentrated and confined) by geologic traps, such as folds and faults. If the reservoir rocks are not naturally permeable enough, it may be necessary to fracture (crack open) them artificially with explosives or with water or gas under high pressure to increase the rate at which oil or gas flows through them.

How Do We Look For It?

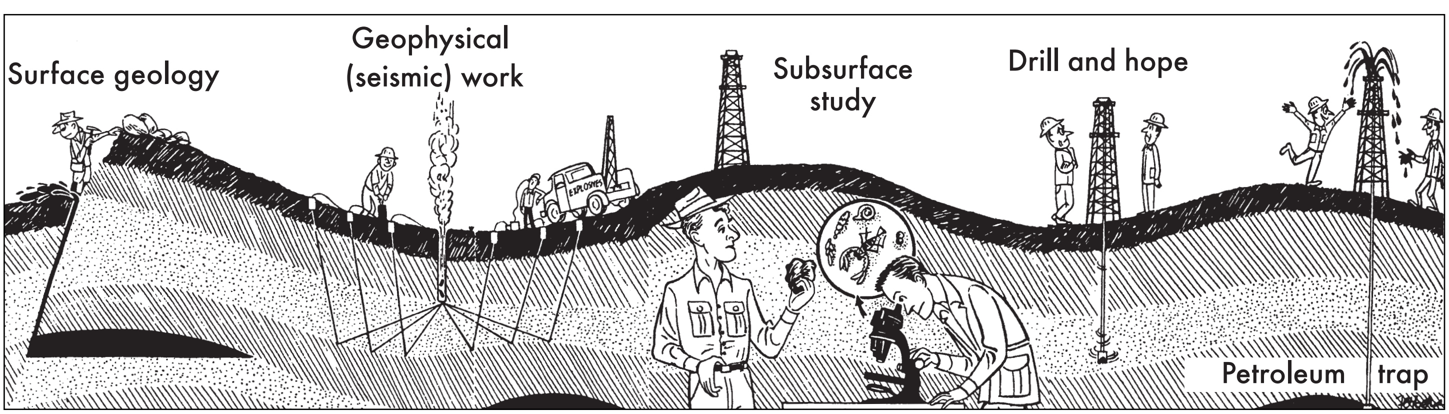
Before any production activity can begin, oil and gas must first be found. For this purpose, the industry relies heavily on exploration, which is the artful application of creative thinking to rigorous science (with a measure of good luck). The geoscience professionals who perform this function are very often the first and most important in the successful discovery of new fields and proving additional reserves.

The search for oil and gas beneath the earth's surface is a risky undertaking. Indeed it is quite a gamble to invest money in an exploration "wildcat" well, because there are so many unknowns involved in the analysis and study of the earth. A number of conditions must exist before an oil or gas accumulation can develop—hydrocarbons must have been generated and they must have migrated to a suitable location to be trapped. Geoscientists use several scientific and technical procedures to "predict" whether these conditions may have combined to create an oil or gas field, but the results are **never** guaranteed.

Not all exploration wells drilled result in the discovery of oil and gas. The success rate can vary from drilling five or ten exploration wells to achieve one successful producing well; it may take as many as 50 or 100 exploration wells to discover a "significant" new oil field. The risk is further increased by the high cost of drilling new wells. In 2002, the average cost of drilling a new well in the United States was nearly $1 million assuming a well depth of 5,000 feet (typical for onshore oil wells).

The high cost of finding new oil and gas fields demands that proper exploration work be completed before extensive drilling is started. The use of exploration techniques to find oil and gas began nearly 150 years ago when Edwin Drake drilled the first successful oil well in Pennsylvania in 1859. Early oil explorers originally looked for oil in seeps and slicks along low places in river valleys and their adjoining creeks. *(See Birth of the Oil Industry in Colorado on page 9.)* Water wells with their occasional oil shows provided additional clues to the existence of petroleum beneath the earth's surface.

It was during this early period that the term "wildcat well" was first used. In those days, the woods of Pennsylvania were full of wild cats (bobcats) and mountain lions. At night, while oil drillers were working on their rigs, the wild cats often could be heard screaming in the woods. As a result, the early exploratory wells drilled in this part of the country became known as "wildcat wells." This term has been used throughout the history of oil exploration, and still refers to those wells that are drilled to find oil and gas in previously unexplored areas.



PETROLEUM PUBLISHERS, 1971

Oil and gas exploration, or the search for oil

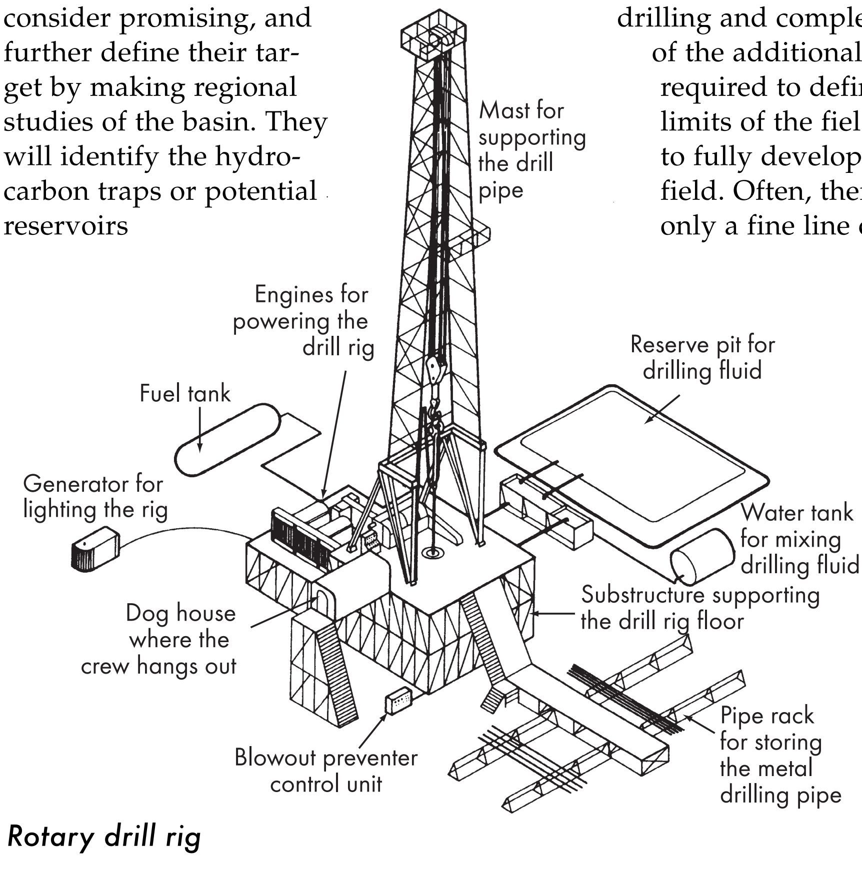
The modern science of exploring for petroleum deposits combines methods of describing the geology that can be observed at the earth's surface with sophisticated subsurface techniques that allow the geoscientist to visualize below the earth's surface. Equally important as the *techniques* themselves, however, is their application to the general exploration *process*. Most exploration goes through a typical cycle or pattern, although more research is required to find new fields than locating extensions of older or existing ones.

The exploration geologist's first task is to choose a general area for exploration. In the United States, there are numerous locations, generally known as sedimentary basins, where major exploration activities are conducted. The Rocky Mountains have many large basins of sedimentary deposits that contain hydrocarbons. *(See Colorado Basin map on page 9.)* Geologists must choose a particular area or basin that they consider promising, and further define their target by making regional studies of the basin. They will identify the hydrocarbon traps or potential reservoirs using both surface and subsurface methods.

Prospects must be well defined in order to obtain oil and gas leases from landowners prior to the drilling of a wildcat well. After the necessary land work has been completed, the next step is to drill test wells to determine whether producible hydrocarbons are present.

Once a successful test well or series of wells has been drilled, the economic potential of the hydrocarbon discovery must be determined. This step includes estimating how much oil and gas is present (reserves), the probable selling price, the cost of continuing the exploration effort as well as the cost of full field development, and the taxes, royalties, and other expenses associated with producing the oil field.

If the venture looks promising, the final step is taken—development of a newly discovered field. At this point, the exploration team may turn the project over to a production team to manage the drilling and completion of the additional wells required to define the limits of the field, and to fully develop the field. Often, there is only a fine line of distinction between the exploration and production teams; they both utilize the same methods and engage in similar activities. Although the production geologist works in areas where oil or gas production has already been established, the geologic problems are no less challenging. New subsurface geological and production information requires constant detailed study and evaluation to ensure that the field is efficiently and completely developed. New information about the reservoir is constantly being accumulated from field production data and engineering studies, and is used to revise and refine the knowledge at hand.



Rotary drill rig

Do We Really Need It? Why?

It seems like a complicated process to go through just to find and produce hydrocarbons! It begs the question—why is it so important? Petroleum plays a significant, even critical role in the modern industrial world. Petroleum products and petrochemicals affect almost every aspect of our civilization and the quality of our lives as individuals, including transportation, food, clothing, shelter, and recreation. The supply, production, and consumption of petroleum influence national economics, and security issues and have a bearing on global politics and international relationships—nations even fight wars over petroleum!

The petroleum industry has attained its present position of importance and prominence in a relatively short span of time. For example, the history of the industry in the United States only dates back to 1859 when the first well drilled specifically for oil proved successful. Since that time, technological advances, along with dramatic social changes, have con-

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tributed to the emergence and growth of the petroleum industry.

Even though the petroleum industry has a relatively short history, the use of petroleum itself extends much further into the past. The knowledge and use of petroleum can be traced back for centuries, and may well pre-date recorded history. Today petroleum has become a vital part of our everyday life and the economics of our nation. Daily, Americans use more than 3,000 products that are derived from petroleum—gasoline, jet and other fuels, aspirin, makeup, synthetic fabrics, and fertilizer to name but a few. Even with conservation efforts, our consumption of petroleum averaged 20 million barrels of oil per day in 2002. Meanwhile, the oil industry has grown to service this need and demand for petroleum in our society. Production of oil in this country was about 2.5 billion barrels in 2002. The United States consumed nearly four billion barrels of oil more than we produced in 2002. Therefore, as a net importer, our nation must concern itself with global issues that affect the long-term outlook for energy supply and demand.

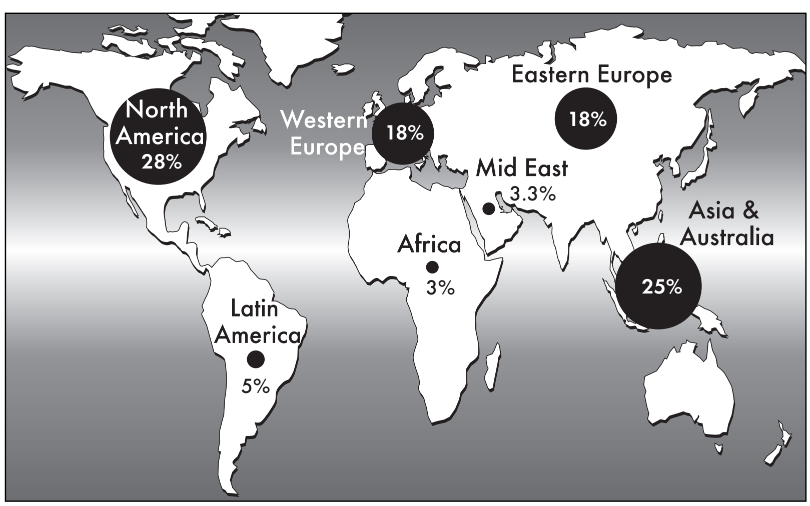
Are We Running Out?

The amount of time required for oil and gas to form is not known precisely. Since virtually no petroleum is found in rocks younger than one to two million years old, geologists infer that the process is comparatively slow (in human terms). Even if it took only a few tens of thousands of years (a geologically short period), the world's oil and gas resources are being used up much faster than significant new supplies can be produced by geologic processes. Therefore, oil and natural gas are considered nonrenewable energy sources.

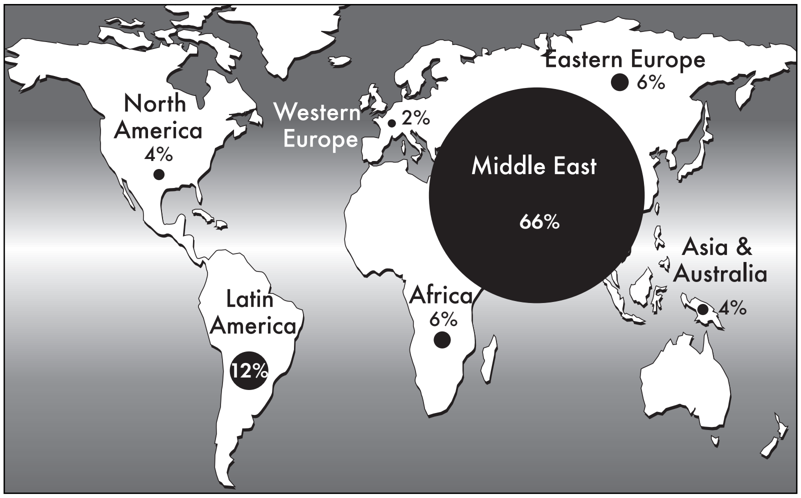
Worldwide, more than 500 billion barrels of oil have been consumed, and the estimated remaining reserves are about one trillion barrels. (One barrel is equal to 42 gallons.) That does not sound too ominous until one realizes that close to half of the consumption has occurred in the last quarter-century or so. Also, global demand continues to increase as more countries advance technologically.

Oil supply and demand are very unevenly distributed around the world. Two-thirds of the world oil reserves are located in the Middle East. In contrast, the United States has only 4 percent of the world oil reserves but consumes over 25 percent of the oil used worldwide—we are the largest consumer in the world.

Since the mid-1970s, the United States has used as much



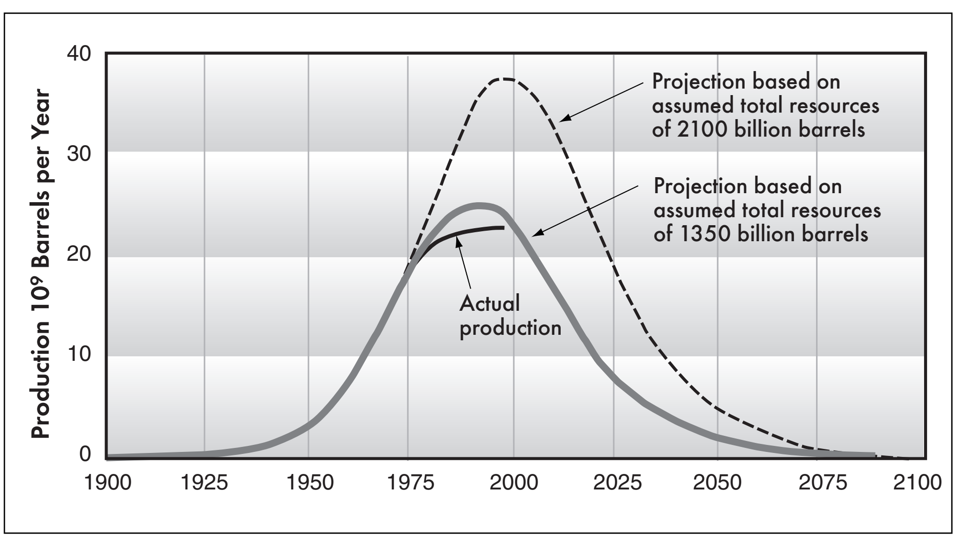
World energy consumption



World oil reserves

domestic oil each year as we have discovered; in many years, we have used more. As a result, U.S. oil reserves are declining. Furthermore, the United States has for many years relied heavily on imported oil to meet part of its energy needs. Currently, more than half the oil we consume is imported from other countries; principal sources are Saudi Arabia, Venezuela, Canada, and Mexico. Simple arithmetic demonstrates that the rate of oil consumption in the United States is very high compared to the estimated total domestic resources available. Some of those resources have yet to be found, however, and will require time to discover and develop.

Both U.S. and world oil supplies could be nearly exhausted within decades especially considering the likely acceleration in world energy demands. Occasionally explorationists do find the rare, very large concentrations of petroleum—the deposits on Alaska's North Slope and beneath Europe's North Sea are examples. Yet even these make only a modest difference in the long-term picture. The Alaskan oil discovery, for instance, represented reserves of about 10 billion barrels—a great deal for a single region, but less than 18 months of current U.S. consumption at our rate. However, large finds such as that in Alaska do reduce U.S. reliance on foreign imports and thus our balance of payments.



Actual world oil production compared to the M. King Hubbert curve published in the early 1970s. *—ENVIRONMENTAL GEOLOGY BY CARLA W. MONTGOMERY*

from the State Geologist continued

ing Boulder. I will not be doing that!

However, I will be trying to help people understand the importance of our natural resources in this state, because part of the CGS's statutory charge is "to promote economic development of mineral resources." Having worked in the natural resources industry for much of my career, I know thousands of people in the industry all over the country. The vast majority of them are hard working, creative, honest women and men who are proud of their environmentally-responsible efforts to supply this country with the energy and resources that we need to live our productive and enjoyable lives.

The petroleum industry in our state is an important element of our economy. As is true throughout the United States, Colorado's oil production has peaked and is in decline. However, a bright spot in this decline is that the creative people in this industry have been able to plateau the decline so that production has remained constant in Colorado for almost five years. Certainly, we cannot turn our decline around in this state, nor can the United States. However, anything that even slows the decline is a plus for lessening our dependence on parts of the world upon which we would prefer not to be dependent.

Environmental Regulations Dealing With Mineral Fuels Extraction

Federal Regulations

Clean Air Act Amendments of 1990 (CAAA)

Clean Water Act (CWA)

National Pollutant Discharge Elimination System (NPDES)

Safe Drinking Water Act (SDWA)

Resource Conservation and Recovery Act (RCRA)

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

Superfund Amendments and Reauthorization Act (SARA Title III)

Environmental Impact Statements (EIS)

National Environmental Policy Act (NEPA)

Endangered Species Act (ESA)

Bureau of Land Management Powers Regarding Wilderness Designation

Federal Land Policy Management Act (FLPMA Section 603)

State Regulations

Interstate Oil and Gas Compact Commission (IOGCC)

Colorado Oil and Gas Conservation Commission (COGCC)

Industry Initiatives

American Petroleum Institute's (API) Strategies for Today's Environmental Partnership (STEP)

Independent Petroleum Association of America (IPAA) Awards for Exemplary and Creative Environmental Programs

Colorado Oil and Gas Conservation Commission's (COGCC) Environmental Award

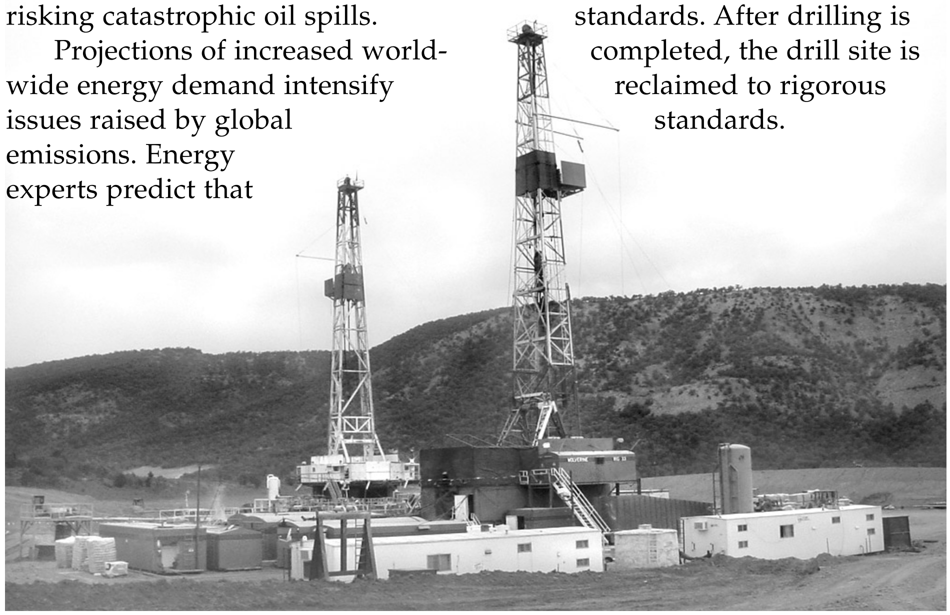
Does Its Use Damage Our Environment?

Environmental issues are important in all segments of the energy industry. Ongoing changes to environmental regulations affect oil and gas extraction, processing and transportation, as well as the industrial, commercial and consumer use of both fuels. There is an increasingly complex relationship between the environmental advantages of natural gas as a heating, vehicular, and electricity-generation fuel, the environmental advantages of domestically produced oil versus foreign-produced oil, and global considerations that impact the oil and natural gas industry in the United States.

The fact that so much of the nation's oil supply comes from outside the United States is subject to criticism on two environmental points: first, production abroad may cause environmental damage because foreign regulations on extraction are generally less stringent than domestic regulations; and second, foreign-produced oil must be shipped to the United States in ocean-going tankers, thus risking catastrophic oil spills.

Projections of increased worldwide energy demand intensify issues raised by global emissions. Energy experts predict that global demand for energy in the next two decades will increase by 50 percent or more, largely as a result of economic growth. The challenge for the natural gas and oil industry is to continue to meet rising demand, while advancing more sophisticated technologies that maximize fuel efficiency and minimize environmental impacts. *(See the article on Carbon Storage on page 14.)*

As with most U.S. business sectors, the oil and gas industry is heavily influenced by federal and state regulations. This is an area in which change is never-ending, as legislative and regulatory bodies continue to fine-tune existing laws to assure a safer environment for all. *(See list of Environmental Regulations at left.)* In Colorado, the Colorado Oil and Gas Conservation Commission (COGCC) regulates the oil and gas industry. The COGCC issues permits for all wells to be drilled, and assures that proper drilling techniques are employed to protect not only the surface but subsurface aquifers as well. If the well is successful and production facilities are installed, the COGCC ensures safe operating standards. After drilling is completed, the drill site is reclaimed to rigorous standards.



Encana Oil and Gas Co. multiple drilling rigs, Garfield County. Modern drilling techniques allow the drilling of several targets from one drill site lessening the environmental impact.—BRIAN MACKE, COGCC

BIRTH OF AN INDUSTRY —

Florence and Boulder Oil Fields

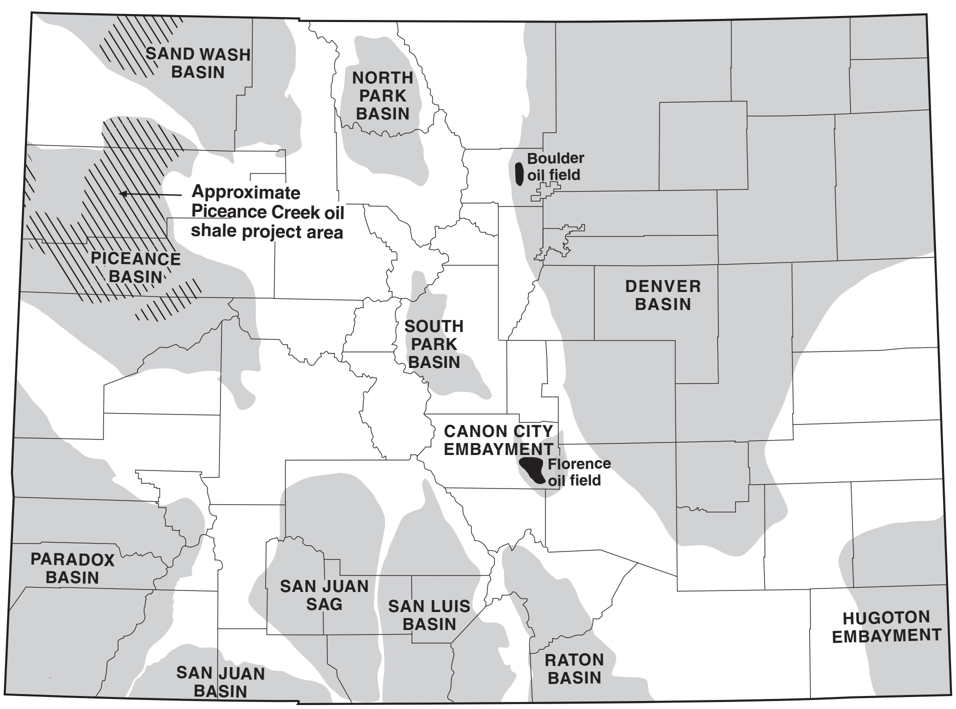
Colorado is rich in natural resources that have been important to the growth and settlement of the state. Our oil industry was born in 1881 with the discovery of the state's first oil field—the Florence field. However, the discovery of this field had its roots in efforts begun over 20 years earlier, in 1860, at an oil spring near Canon City.

The Ute Indians were among the first to discover oil in Colorado. Oil from a seep found along one of the tributaries to the Arkansas River was used for medicine and war paint. This tributary became known as Oil Creek.

Western expansion was triggered by episodes of gold fever and brought more people into Colorado. By 1860, Canon City was established as a major trading center for gold mining camps in the mountains, such as Leadville. Gold mining activity in the area put many people in proximity to visible surface occurrences of oil.

There was a growing demand for better and cheaper sources of lighting in homes. Whale oil was excellent, but at $2.50 per gallon, it was too expensive for most people. Alcohol lamps were bright but dangerous, and tallow candles were dim and smoky. Crude oil had begun to attract attention, but it so far had only limited uses as a medicine and a lubricant.

By 1855, the first scientific report was published on the chemistry of petroleum and its possibilities for illumination. The search led to the development of kerosene—a fuel for lanterns distilled from crude oil. The manufacture of kerosene was the first widespread use of crude oil. As kerosene use increased, new larger sources of crude oil were sought. The



Colorado oil and gas basins. Green River Formation oil shale deposits shown by hachures. The richest and most easily recoverable deposits are located in the Piceance Creek Basin.

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RockTalk
is published by the
Colorado Geological Survey
1313 Sherman Street,
Room 715, Denver, CO 80203

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Florence oil field circa 1890 –DENVER PUBLIC LIBRARY, WESTERN HISTORY COLLECTION, UNKNOWN PHOTOGRAPHER, NO. X-8442

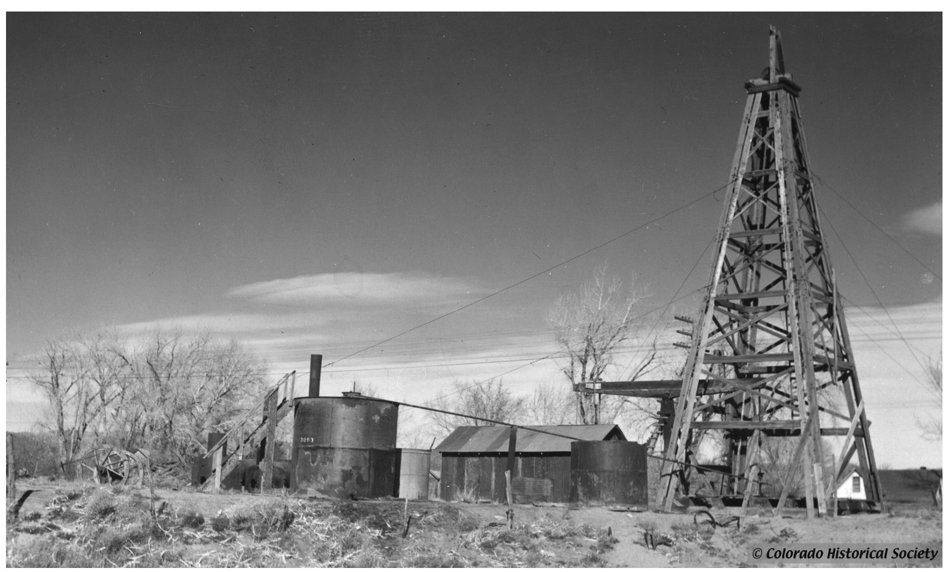
several wells in the area and his operations produced refined kerosene from the oil gathered from the spring. Because of shortages caused by the Civil War, peak prices for kerosene in Denver were $1.25 to $2.85 per gallon—and you think our gasoline prices are high!

Cassidy and his partners sold the spring for $135,000 to a Boston investor group which, despite their attempt to dig shafts on the property and to sink deep wells, was never able to find any oil at depth. The spring continued to seep at the rate of one barrel per day no matter what they did. The Oil Spring site was worked sporadically from 1870 to 1950. Only about 3,000 gallons of kerosene were refined from the crude oil gathered at the Oil Spring site. Although this does not qualify as an oil field, the site is very important from a historical standpoint. It provided the first clues to oil hunters that larger oil resources may exist in the area.

Gold fever brought people to the Florence/Canon City area, and the nearly simultaneous discovery of black gold back east drew attention to the Oil Spring. Railroads helped accelerate the westward expansion of the states. By 1870, John D. Rockefeller had founded Standard Oil Company of Ohio (in Cleveland) and had begun to acquire controlling interests in all aspects

first oil well was drilled in 1859 on Oil Creek near Titusville, Pennsylvania. It produced about 30 barrels of oil per day from a depth of 69 feet. Thus the modern petroleum industry was born. Just 13 months after this first well was drilled, a second oil discovery was reported on another stream named Oil Creek. This one, however, was located over 1,000 miles to the west near Canon City, which was then in the Kansas Territory. On September 8, 1860, the *Canon Times* reported that Gabriel Bowen had recorded a claim for his discovery of an oil spring about eight miles northeast of Canon City. His claim was said to have flowed five gallons per hour from the Morrison Formation. The site became known as Oil Spring.

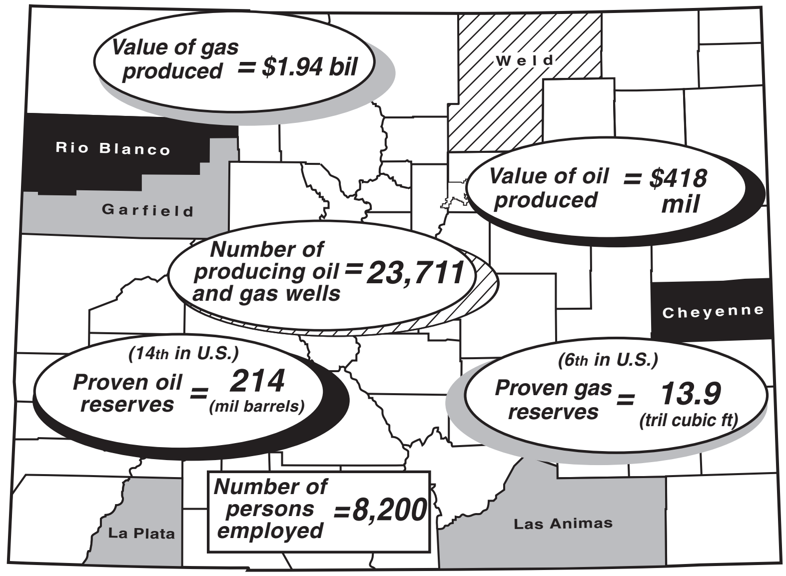
Soon after Bowen recorded his claim, Dr. J.L. Dunn immediately developed Oil Spring by digging four pits into the river alluvium. One yielded a flow of about a barrel per day, two had a scum of oil, and the fourth was just water. Thus the initial effort at Oil Spring was not profitable. Not long after Dunn's unsuccessful efforts, the Oil Spring mineral claim was sold to a group of men led by a professional promoter, Alexander Cassidy. Cassidy drilled



Colorado oil derrick–COLORADO HISTORICAL SOCIETY

COLORADO PETROLEUM PROFILE

E*nergy Information Agency News Release August 2003*—Colorado requires oxygenated gasoline in the contiguous metropolitan areas stretching from Denver to Fort Collins. Colorado ranks 12th in crude oil production with volumes totaling 49,000 barrels per day, and ranks 13th in crude oil proved reserves. The state's two petroleum refineries have a combined crude oil distillation capacity of 89,000 barrels per calendar day, and the State is served by several crude oil, product, and liquefied petroleum gas (LPG) pipelines. Colorado has the second highest percentage of homes heated with natural gas with a market share of almost 75 percent. The second most popular heating fuel is electricity with a market share totaling 16 percent.



Top producing counties: oil (black), gas (gray), oil and gas (striped); represents values as of 2002

Fuel Facts

General Overview

Population: 4,506,542 (2002), ranked 22nd

Per Capita Income: $33,276 (2002), ranked 10th

Total Energy Consumption: 1.2 quadrillion British thermal units (Btu) (2000), ranked 27th

Per Capita Energy Consumption: 279 million Btu (2000), ranked 41st

Total Petroleum Consumption: 9.8 million gallons per day (2000), ranked 28th

Gasoline Consumption: 5.5 million gallons per day (2000), ranked 26th

Distillate Fuel Consumption: 2.0 million gallons per day (2000), ranked 31st

Liquefied Petroleum Gas Consumption: 0.7 million gallons per day (2000) ranked 23rd

Jet Fuel Consumption: 0.9 million gallons per day (2000), ranked 23rd

Petroleum Supply (Upstream)

Crude Oil Proved Reserves: 196 million barrels (2001), ranked 12th (13th including Federal Offshore). Accounts for 1% of U.S. crude oil proved reserves.

Crude Oil Production: 49,000 barrels per day (2002), ranked 11th (12th including Federal Offshore). Accounts for 1% of U.S. crude oil production

Total Producing Oil Wells: 5,643 (2002)

Rotary Rigs in Operation: 28 (2002)

Transportation—Major Pipelines

Crude Oil: Amoco, Conoco, Unocal, Ultramar Diamond Shamrock

Product: Chase, Kaneb, Phillips, Sinclair, Ultramar Diamond Shamrock

Liquefied Petroleum Gas: Amoco, Phillips

Refining and Marketing (Downstream)

Refineries: Distillation capacity of 87,000 barrels per calendar day (BCD) (2003)

Colorado Refining Company—Commerce City at 27,000 BCD

Suncor (previously Conoco Refinery)—Commerce City at 60,000 BCD

Gasoline Stations: 2,234 outlets (2003), or about 1.3 percent of U.S. total

of the business. The petroleum industry began to grow into big business and Rockefeller built a monopoly. Continental Oil Company also marketed eastern-refined products to the West. Keep in mind that during the 1860s and 1870s, oil was not used as it is today, to make gasoline for automobiles. Back then oil was used to make kerosene, wax, candles, lubricating oil, and grease.

In 1880, while working on a coal lease near Florence, Cassidy, his son, and the driller, Issac Canfield drilled a well supposedly to produce water. In January 1881, they hit oil at a depth of 1,445 feet. Within a year, three separate companies were drilling, and the Florence oil field was on its way to fame and a long history of production, eventually involving both the Continental Oil Company and the Standard Oil Comproduced 15 million barrels of oil; most of it produced between 1890 and 1920. Wells drilled in the area totaled 500, and in the 1920s, the field was extended to Canon City. The wells in the Florence field are pumped and generally only yield a few barrels per day, with only 2,000- to 3,000-barrels of oil produced in their lifetime. No more than 50 wells were considered prolific, but there was always the hope that the next well drilled would be the big one.

Today, little remains of the former glory of the Florence oil field. The first thing that took the "bloom off the boom" in Florence was the diversion of ore milling to Colorado Springs, that was followed by the closure of coal mines, declining oil production, and the transfer of refining to a new state-of-the-art refinery, built in the 1930s, in Commerce City. By 1936, the Continental Oil (Conoco) refinery had closed in Florence, along with two other refineries. Although production is minimal, the Florence field still produces today.

Boulder oil field, 1900–1920—DENVER PUBLIC LIBRARY, WESTERN HISTORY COLLECTION, BY L.C. MCCLURE, NO. MCC-1615

pany. Although the product refined from Florence crude was valuable due to its high illuminating oil content, early field development was limited by the high cost of shipping the refined products to distant markets. Two local companies were most active in the field—United Oil Company and Florence Oil and Refining. Both had refineries on the east end of the town of Florence. In 1888, Continental bought a minority interest in United Oil and, by distributing locally refined products, made it possible to avoid high transportation costs from the east.

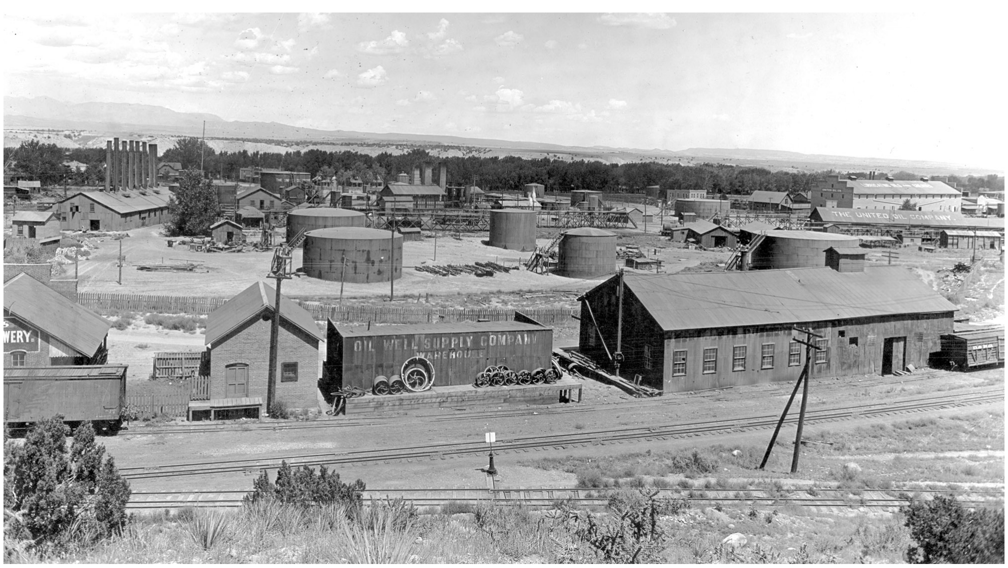
By the turn of the century, Florence had grown to a population of 10,000 and the streets were crowded day and night. At the height of the boom, there were 25 oil companies, three refineries, seven gold ore mills, and more than two dozen coal mines. The oil field covered about 25 square miles. Oil production from the field reached a peak of 3,000 barrels per day in the 1890s. Since its discovery in 1881, the Florence oil field has

What makes the Florence field so unique is that the oil it produced came from fractures found in Pierre Shale at the structural bottom of the Canon City Embayment.

About 100 miles north of Florence, the Boulder oil field was discovered in 1901, two decades after Florence. It is the second oldest field in Colorado, and now boasts one of the oldest producing wells in the West.

Issac Canfield was the driller who worked on the Florence field discovery in 1881. He was later attracted to the Boulder area by its topographic similarity to Florence, and by oil seeps and "smelly" rocks. He discovered the Boulder oil field using a dowsing rod.

The field was developed using cable-tool drilling, similar to the method used by Drake in drilling for his first discovery of



Oil refineries at Florence, 1895–1920.
—COLORADO HISTORICAL SOCIETY, DENVER AND RIO GRANDE COLLECTION

First tank of oil from McKenzie well in Boulder oil field—COLORADO HISTORICAL SOCIETY

oil in Pennsylvania in 1859. The well was placed on a pump and produced between 60 and 400 barrels of oil per day from a depth of about 2,500 feet. Well problems led to the drilling of a second twin well, the McKenzie No. 1-21. It was the first commercial well in the field and today, this 100-year-old well is still producing about one-half barrel of oil per day.

The discovery brought an exciting boom to the Boulder area where 100 wells were drilled in the first four to five years. Over a hundred oil companies were doing business in Boulder during this time with names like Left Hand, Millionaire, Gnome, Boulder Belle, but also predecessors of the companies that have today become BP/Amoco and Conoco/Phillips. Ultimately 200 wells were drilled; more than half were dry holes.

Investors were promised "Oil or Money Refunded," but few made money and Canfield got out early. Bertle Langridge, a professor at CU, raised $500,000 from eastern investors and in 1904 became the Territorial Geologist. Soaring real estate prices and land speculation in oil leases were all part of the great oil boom.

Like the Florence field, the producing interval is the Pierre Shale. It consists of fractured shales and thin, shaly sandstones, including the Hygiene Sandstone; these are some of the same rocks that produce elsewhere in the Denver Basin. Boulder field produces from an anticline, which is the classic type of geologic structure for trapping oil. The Boulder oil field's best production was related to fracturing on the crest and trough of the structure. Fracturing (or maximum bending of the rocks) proved difficult to predict and reservoir performance was generally moderate.

The field reached its peak of 85,000 barrels of oil per year in 1909, as the fractures rapidly flushed their oil. Since then, there has been a long decline in production, and individual wells have generally produced fewer than 10 barrels of oil per day over the last 50 years.

One hundred years ago, operators sold the produced oil to refineries in Boulder and Denver for $1 per barrel. It was a light, "sweet" (low sulfur content) crude. The greatest impact on Boulder was growth, as population nearly doubled in the decade following the oil discovery. Some predicted that the "sea of derricks" east of Boulder in 1902 would ultimately stretch to the Wyoming line.

The McKenzie discovery well now sits on a 20-acre property that is surrounded by state highways. There have been several attempts to develop the parcel. In November 2002, the Boulder City Council granted historic landmark status to the well. Efforts are underway to properly preserve this piece of history.

SOURCES: Matt Silverman and Rocky Mountain Association of Geologists' *Lighting the Frontier* video.

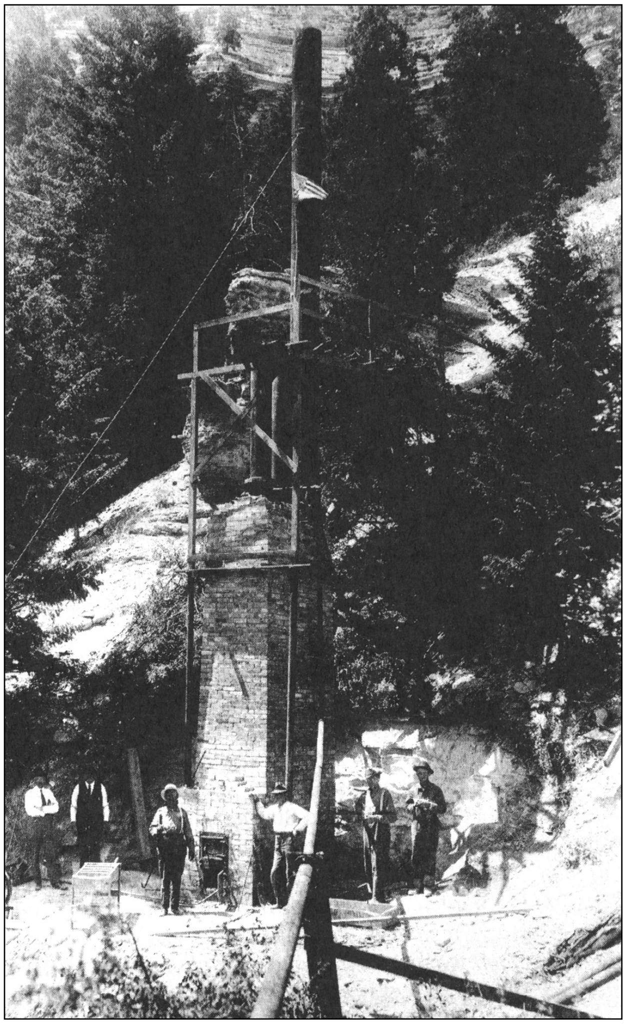
OIL SHALE—ENORMOUS POTENTIAL BUT...?

Colorado was dramatically impacted by the boundless enthusiasm that began in the 1970s as the United States attempted to unlock the enormous resource potential of oil shale in Colorado. A news release from the late 1960s stated, "Tucked beneath the peaks and buttes of western Colorado lies enough oil to keep the United States rolling along at its current gas-guzzling rate for another 500 years." This was not new news, at least not to those in Colorado.

A 19th century settler in the valley of Parachute Creek in western Colorado built a log cabin and made the fireplace and chimney out of the easily cut, locally abundant black rock. The pioneer invited a few neighbors to a house warming. As the celebration began, he lit a fire. The fireplace, chimney, and ultimately the whole cabin caught fire, and burned to the ground. This handsome black rock chimney was made of oil shale. It was a sensational house warming!

It was not until World War I that interest was aroused in the oil shale deposits of the western United States. Between 1916 and 1920, some 20,000 placer-mining claims were filed on nearly all the oil shale land in Colorado, Wyoming, and Utah. By the end of World War II, most of the oil shale property had been purchased by four large oil companies, among them Standard Oil Company (Chevron) and Union Oil Company (Unocal), both of California. Shell Oil began to purchase oil shale property in the early 1950s. In response to the 1973 Arab oil embargo and sharply increasing oil prices, the U.S. Department of the Interior began an oil shale leasing program in 1974 in the oil shale regions of Colorado and Utah on federal lands. By the early 1980s, nearly all of the major oil companies had established pilot projects to tackle the technical challenges of extracting oil from oil shale.

Colorado learned of oil shales' economic and technical problems on May 2, 1982, a day still remembered as "Black Sunday," when Exxon suddenly pulled the plug on its multibillion-dollar Colony Oil Shale Project near Parachute. The overnight closure left more than 2,000 workers unemployed and created a wave of bankruptcies, foreclosures and business failures on the Western Slope. Exxon, Unocal, Shell Oil and other smaller players never produced a profitable barrel of synthetic crude from oil shale.



The first oil shale retort in Colorado. At one time during the 1920s, over 80 experimental retorts were in operation in the oil shale region of the Western U.S. However, the plentiful supply of crude oil which began to appear after 1925 as new oil fields were found, caused interest in shale to dwindle and substantial activity was not renewed again until World War II.—1918, U.S. GEOLOGICAL SURVEY

Oil shale is very poorly named. The rock, while always sedimentary, need not be shale, and the hydrocarbon in it is not oil! The potential fuel in oil shale is a sometimes-waxy solid called kerogen, which is formed from the remains of plants, algae, and bacteria. The physical properties of kerogen dictate that the oil shale must be crushed and heated to distill out the hydrocarbon known as "shale oil," which then is refined similar to crude oil to produce various liquid petroleum products.

The United States has about two-thirds of the world's known supply of oil shale—for a total estimated resource of 2- to 5-trillion barrels. The richest of these deposits is the Green River Formation, which is estimated to contain more than 560 billion barrels of recoverable oil. *(See Piceance Creek Basin on map on page 9.)* For a number of reasons, the United States is not yet using this apparently vast resource to any significant extent, and it may not be able to do so in the near future.

One reason for this is that much of the kerogen is so widely dispersed through the oil shale that huge volumes of rock must be processed to obtain moderate amounts of Colorado shale oil. Even the richest oil shale yields only about 30 gallons of shale oil per ton of rock processed. The cost is not presently competitive with that of conventional petroleum, and was not competitive even at the peak oil prices of the 1980s. Nor have large-scale processing facilities been built—present plants are strictly experimental. More efficient and cheaper processing technologies are needed.

Another problem is that a large part of the oil shale is located at or near the surface. Therefore, at present, the economical way to mine it appears to be surface- or strip-mining with its associated land disturbance. Most of the richest oil shale is located in areas of the western United States that are already chronically short of water, making revegetation after strip-mining difficult. Some consideration has been given to *in situ* heating and extraction of the kerogen without mining in order to minimize land disruption, but the necessary technology is poorly developed, and the process leaves much of the fuel behind.

The water shortage presents a further problem. Current processing technologies require large amounts of water, on the order of three barrels of water per barrel of shale oil produced. Just as water for reclamation is in short supply in the West, so too is the water to process the oil shale.

Finally, since the volume of the rock actually increases during processing, it is possible to end up with a 20 to 30 percent larger volume of waste rock to dispose of than the original volume of rock mined.

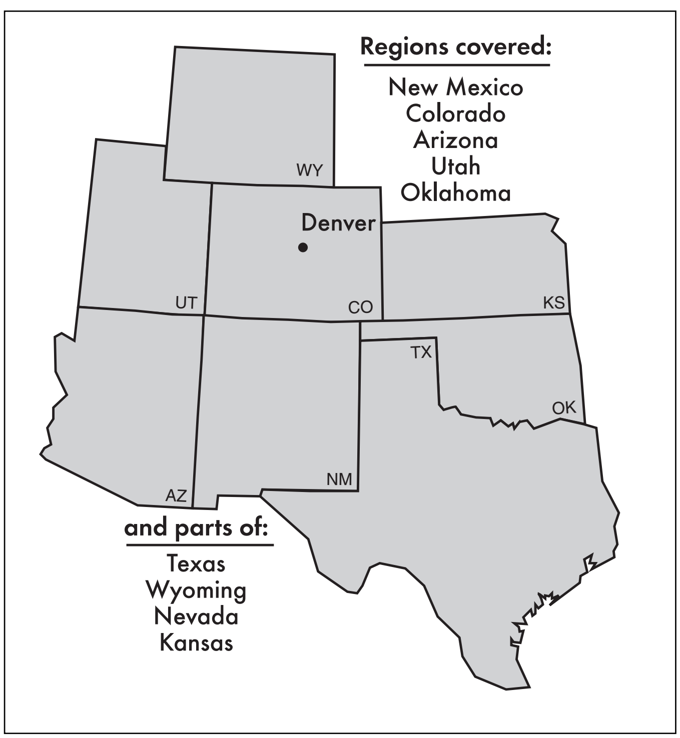
Scientists and economists differ widely in the extent to which they see oil shale as a promising alternative to conventional oil and gas. Certainly, the water-shortage, waste-disposal, and land-reclamation problems will have to be solved before shale oil can be used on a large scale. Also, the lower oil prices fall, the less competitive oil shale becomes. It is unlikely that those problems can be solved within the next few decades, although over the longer term, oil shale may become an important resource.

These hurdles are not stopping Shell Oil from returning to Rio Blanco County in western Colorado with an experimental technique that may one day prove economically feasible. Shell is suspending electrical heaters in wells drilled into the oil shale. The heated oil can then be pumped to the surface. This underground process creates less surface disturbance and eliminates the problem of spent shale disposal. Although still in the experimental phase, the low environmental-impact technique may become economic at some time in the future.

CARBON STORAGE IN THE ROCKIES—
How Do We Address the Challenges?

In August 2003, the U.S. Department of Energy and its National Energy Technology Laboratory announced a new program to manage the effects of carbon emissions. This new technology is called carbon sequestration. Carbon sequestration involves both the capture and storage of carbon emissions from fossil fuel use so that carbon dioxide (CO_2) is not released into the atmosphere. Although carbon sequestration occurs naturally in the environment—for example, trees take in carbon naturally—new technology has been developed to complement these natural processes.

As a result of this new technological possibility, the Department of Energy is leading a nationwide effort to test the feasibility of sequestering carbon. Seven regional partnerships are looking for the specific areas in the country most environmentally and socially suitable to store the sequestered carbon. These seven partnerships are comprised of 140 government and non-government organizations in 33 states, three Indian nations, and two Canadian provinces. Each partnership is led by one of the participating organizations to evaluate various sequestration approaches and the regulations and infrastructure necessary for wide scale capturing and storage of carbon.



Southwest Partnership states

The Colorado Geological Survey is participating in the Southwest Regional Partnership, whose primary goal is to determine an optimum strategy for minimizing greenhouse gas intensity in the southwest. The Southwest Partnership is led by the New Mexico Institute of Mining and Technology, and comprises a large, diverse group of expert organizations and individuals specializing in carbon sequestration science and engineering, as well as public policy and outreach. These partners include 21 state government agencies and universities, five major electric utility industries, several oil, gas and coal companies, three federal agencies, the Navajo Nation and several non-government organizations.

In the absence of action, annual CO_2 emissions in the Southwest Partnership Region are expected to rise from 500 million tons per year (2001) to nearly 750 million tons per year by 2012. The region can offset much of this growth through various sequestration technologies. One such technology is flue gas CO_2 sequestration from the numerous large coal-fired plants; there are also diverse terrestrial, geologic, and mineralization options available. The partnership is laying out the framework necessary for assessing optimum sequestration strategies for the Southwest Region. The main approach includes: dissemination of existing regulatory/permitting requirements; assessing and initiating public acceptance of possible sequestration approaches; and evaluation and ranking of the most appropriate sequestration technologies for capture and storage of CO_2 in the Southwest Region.

Geologic storage options in the Southwest Region include coal beds, natural CO_2 fields, depleted and marginal oil fields, and deep saline aquifers. One option that the Partnership will explore is the viability of supplanting the CO_2 currently produced from natural CO_2 reservoirs (used for improved oil recovery and enhanced coalbed methane applications) with CO_2 emitted primarily from power plants. In some parts of the Southwest Region it will be important to evaluate the tradeoffs associated with using saline aquifers as CO_2 sequestration reservoirs when they might ultimately be needed as a source of potable, post-desalination water for human consumption in this rapidly growing region.

Environmental and social consequences are associated with each of these options. Quantifying the consequences is challenging because complex interrelationships link the economy, energy production, population growth, greenhouse gas emissions, and the environment. A dynamic simulation model will be used to quantitatively compare alternative sequestration technologies relative to their associated environmental risks, monitoring and verification requirements, life-cycle cost, and applicable regulatory and permitting constraints. The resultant decision model will be used in: scenario development where policy makers and regulators explore a range of "what if" scenarios; constituency development wherein industry representatives and other partners can examine the scenario results as a test of their viability and ability to be implemented; and outreach and education where the model will be taken directly to the public and used as an aid to improve their understanding of CO_2/energy cycle issues.

Establishing and communicating the consequences and tradeoffs between alternative, emissions-reduction strategies is the initial step required in formulating an effective and publicly acceptable sequestration program. As additional details about the project become available, they may be accessed on the Partnership's Web site at *http://southwestcarbonpartnership.org/*.

—Genevieve Young

ROCK TALK

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