Chapter 3

Natural Gas Basics

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This chapter briefly describes basic theories and terminology used within the report—i.e., it briefly describes what natural gas is, how it is formed, how it is found and subsequently produced, and how discoveries are reported. Words in boldface are defined in the glossary at the end of the technical memorandum. *Readers familiar with basic terminology and concepts of natural gas supply may wish to skip this section.*

WHAT IS NATURAL GAS?

As its name implies, natural gas is a naturally occurring mixture of hydrocarbon and nonhydrocarbon gases found in subsurface reservoirs within the Earth's crust. Methane (CH_4), a light hydrocarbon, is the primary constituent of natural gas and of principal interest to the energy industry. Associated heavier hydrocarbons such as ethane, propane, and butane and impurities such as water, hydrogen sulfide, and nitrogen occur with the methane. If the concentrations of these other constituents render the gas unmarketable, they must be removed prior to use.

HOW DOES NATURAL GAS FORM?

There is no universally accepted explanation of how natural gas formed. Most hydrocarbon deposits of significant size occur in sedimentary basins, however, and are thought to have originated from the decay and alteration of organic matter. Hundreds of millions of years ago, seas that covered a large portion of the land exposed today were inhabited by tiny plants and animals that, upon dying, sank to the bottom and were buried under layers of sediment. In areas of rapid sedimentation, organic decay was accompanied by high pressures and temperatures which, over millions of years, effectively "cooked" the organic material into petroleum (oil and natural gas). Hydrocarbons could also have been formed by other processes: by the anaerobic (without oxygen) digestion of organic materials by bacteria, and inorganically by the reduction of inorganic carbon and its oxides at high pressures and temperatures deep within the Earth. The quantity of recoverable gas thought to have originated by these processes is generally felt to be small, but some controversy still exists, especially concerning the inorganic processes.

Temperature and pressure conditions have a critical role in determining the physical state of the hydrocarbons that result. Natural gas may be found at all depths, but it originated mostly in rocks subjected to particularly high temperatures and pressures over long periods of time. It generally is the only hydrocarbon present at depths beyond 16,000 ft. Liquid hydrocarbons occur at shallower depths, from about 2,500 to 16,000 ft, where lower temperatures are characteristic.[1] Most crude oil is found between 6,500 and 9,000 ft, with light hydrocarbon liquids occurring at depths greater than 9,500 ft.[2]

[1]H. Douglas Klemme, *Geothermal Gradients, Heat Flow, and Hydrocarbon Recovery. Petroleum and Global Tectonics* (Princeton and Landon: Princeton University Press, 1975), p. 260. Cited in Jensen Associates, Inc., *Understanding Natural Gas Supply* in the *U. S.*, contractor report to OTA, April 1983.

[2]B. P. Tissot and D. H. Welte, *Petroleum Formation and Occurrence (New* York: Springer-Verlag, 1978), p. 202. Cited in Jensen Associates, Inc., op. cit.

WHERE IS NATURAL GAS FOUND?

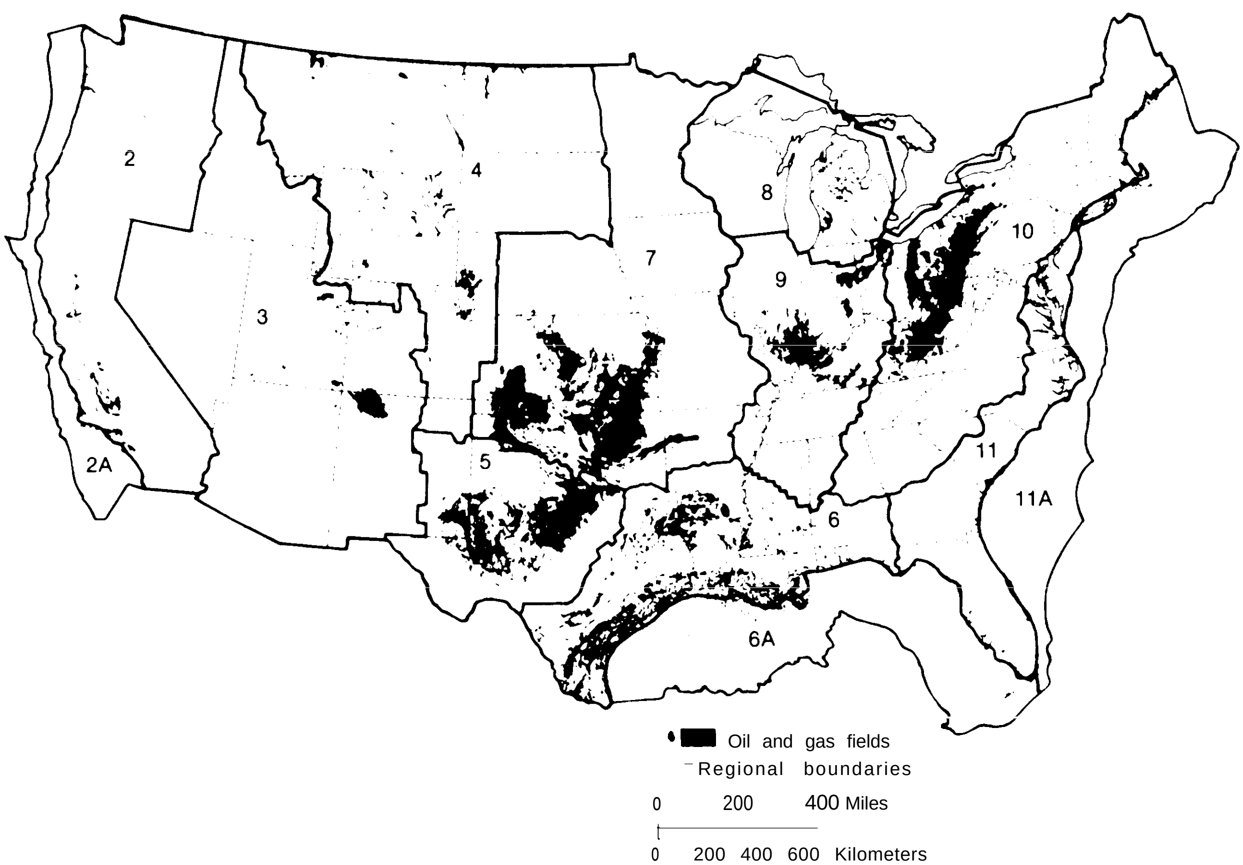
Petroleum accumulations occur as reservoirs or pools—not in caverns or large holes in a rock mass but in the minute pore spaces between the particles that compose the rock. The greater the amount of pore space in the rock (porosity), the larger the quantity of gas or oil that may be contained within it. Pools often occur together in a field, and multiple fields in similar geologic environments constitute a province.

Gas occurs separate from (nonassociated gas) and together with oil. When together, it occurs in solution with the oil (dissolved gas) or as free gas (associated gas), in a gas cap when no more gas can be held in solution under the pressure and temperature conditions of the reservoir.

The search for hydrocarbon accumulations is narrowed by the requirement for the presence of organic material in the sediment at the time of burial. Sedimentary basins are the areas most likely to have contained the organic-rich rocks—source rocks—required for petroleum formation. Sedimentary rocks compose about 75 percent of the exposed rocks at the surface, but only 5 percent of the Earth's crust (outer 10 miles) . The known oil- and gas-bearing areas in the United States are identified in figure 3.

Although source rocks are required for petroleum formation, commercial petroleum accumulations are not usually found in the source rock. Source rocks are generally too impermeable, meaning the texture of the source rock does not allow petroleum to flow easily through the pores to a producing well. Typically, after the petroleum was formed, the gases and fluids (oil and formation water) migrated from the source bed to a more permeable rock, called the "reservoir rock" (this process is called "primary migration"). The fluids moved in the path of least resistance (or

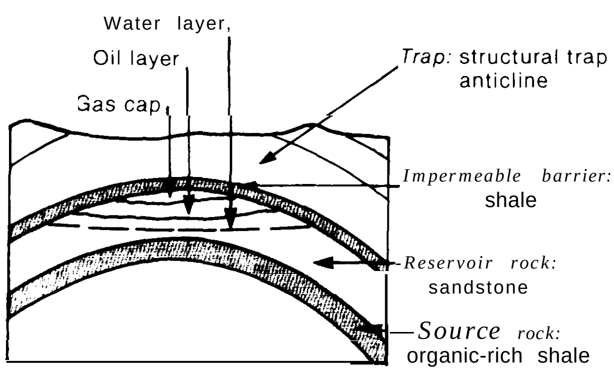
Figure 3.— Known Oil- and Gas-Bearing Areas in the Lower 48 States



SOURCE *Estimates of Undiscovered Recoverable Convention/ Resources of Oil and Gas in the United States,* U S Geological Survey Circular 880, 1981 highest permeability) and continued migrating within the reservoir rock (secondary migration) until an impermeable barrier was encountered, which prohibited further migration into adjacent or overlying rock units or formations. The petroleum then migrated further along the barrier to a place of accumulation, called a trap—usually located at the highest point where the reservoir rock contacts the more impermeable, barrier rock. The four requirements for a hydrocarbon accumulation—a source rock, reservoir rock, impermeable barrier rock, and trap—are illustrated in figure 4.

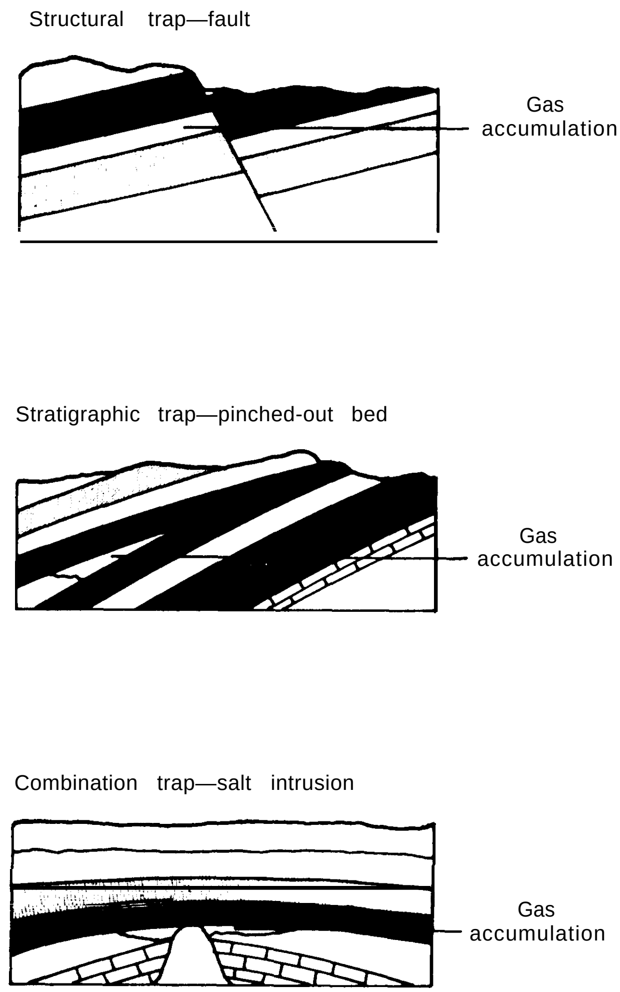
There are three basic types of petroleum traps: structural, stratigraphic, and combination (see fig. 5). Structural traps are formed by earth movements that deform *or* rupture rock strata, thereby creating favorable locations for hydrocarbons to accumulate. Such structural features as faults and anticlines create enclosures that serve as loci for migrating petroleum. Stratigraphic traps are created by permeability and porosity changes characteristic of the alternating rock layers that result from the sedimentation process. In stratigraphic traps, pinched-out beds, sandbars, or reefs serve as reservoirs for migrating petroleum. Combination traps result from both structural and stratigraphic conditions. An example of a combination trap *is* one that results from a salt dome intrusion during deposition that alters the thickness of the strata deposited.

Figure 4.— Four Requirements for Petroleum Accumulation



SOURCE Office of Technology Assessment

Figure 5.—Trapping Mechanisms



SOURCE Off Ice of Technology Assessment

HOW IS NATURAL GAS DISCOVERED?

Before an understanding of subsurface geology was acquired or rules of petroleum occurrence were established, petroleum discoveries were based on surface seeps, knowledge gained from water-well drilling, and luck. Today there are a variety of concepts, exploration methods, and instruments available to help geologists locate subsurface hydrocarbon accumulations.

The type of exploration techniques used varies between sites and depends on how much is known about the area being explored. In areas where little is known about the subsurface, reconnaissance techniques—which provide limited information over a large area—are used to identify favorable areas that warrant more detailed investigation. Satellite and high-altitude imagery sometimes reveals large geologic features or trends that are surface expressions of subsurface geologic structure. Magnetic and gravity surveys detect changes in the magnetic or density properties of the Earth's crust and are also used to infer subsurface structure.

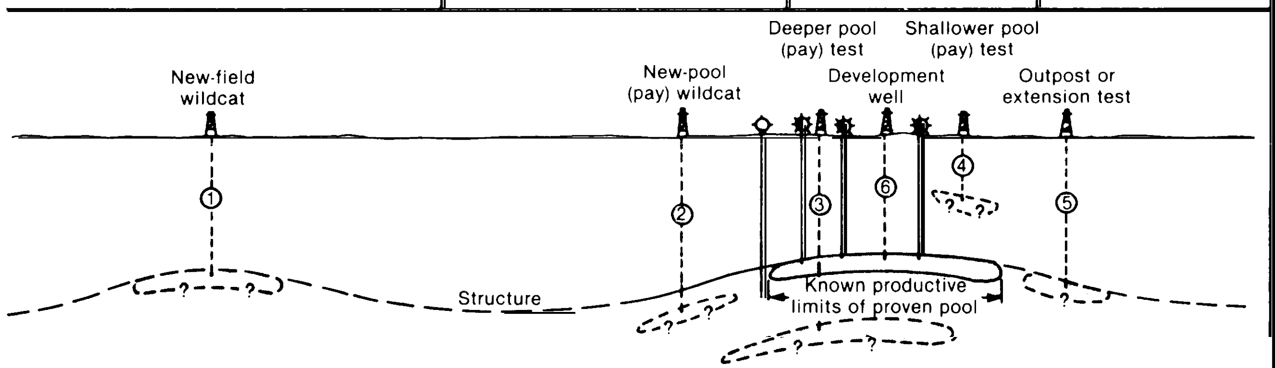
Once a promising area has been identified, more detailed, higher resolution exploratory techniques are used to locate individual prospects for the drill and to project conceptually related groups of prospects, or plays. The seismic reflection method, which measures and interprets the reflections of sound waves off of geologic discontinuities, is particularly effective for providing detailed subsurface information. Drilling is the final stage of the exploratory effort and the only sure way to determine if hydrocarbon-filled reservoirs exist in the subsurface.

In some basins, drilling may be performed so cheaply that predrilling exploration expenditures for seismic surveys and other analyses are not justified. These shallow areas are becoming increasingly scarce, and the role of predrilling exploration analysis is increasing in importance, particularly in frontier areas. If these high-cost areas are to be drilled, operators must be relatively sure that the drilling expense is justified.

The degree of risk involved in drilling depends on how much is known about the subsurface at the drill site, As illustrated in figure 6, a classification scheme has been established to categorize the exploratory wells based on their relationship to

Figure 6.—AAPG and API Classification of Wells

Objective of drilling				Initial classification when drilling is started	Final classification after completion or abandonment: Successful		Unsuccessful	
Drilling for a new field on a structure or in an environment never before productive				1. New-field wildcat	New-field discovery wildcat		Dry new-field wildcat	
Drilling for a new pool on a structure or in a geological environment already productive	New pool tests	Drilling outside limits of a proved area of pool		2. New-pool (pay) wildcat	New-pool discovery wells (sometimes extension wells)	New-pool discovery wildcat	Dry new-pool tests	Dry new-pool wildcat
		Drilling inside limits of proved area of pool	For a new pool above deepest proven pool	3. Deeper pool (pay) test		Deeper pool discovery well		Dry deeper pool test
			For a new pool below deepest proven pool	4. Shallower pool (pay) test		Shallower pool discovery well		Dry shallower pool test
Drilling for long extension of a partly developed pool				5. Outpost or extension test	Extension well *(sometimes a new-pool discovery well)*		Dry outpost or dry extension test	
Drilling to exploit or develop a hydrocarbon accumulation discovered by previous drilling				6. Development well	Development well		Dry development well	



SOURCE Lahee classification of wells as applied by the Committee on Statistics of Drilling of the American Association of Petroleum Geologists and the American Petroleum Institute Developed by Frederic H Lahee in 1944 known petroleum discoveries. There are three basic kinds of exploratory well. A new field wildcat is a well drilled in search of a new field, that is, in a geologic structural feature or environment that has never been proven productive. New field wildcats generally have the greatest associated risk because they are drilled based on the least pre-existing knowledge. New pool wildcats-in search of pools above (shallower), below (deeper), or outside the areal limits of already known pools—are generally less risky because the field in which they are drilled has been proven productive. Outpost and extension tests are drilled to determine the bounds of known pools. Development wells are the least risky because their primary function is to extract the petroleum from the already proven pools; they are not exploratory wells.

When an exploratory well encounters petroleum, the quantity of proved reserves is estimated, and the commercial viability of the reservoir evaluated. Proved reserves are determined by analyzing actual production data or the results of conclusive formation tests. The proved area is the area that has been delineated by drilling and the adjoining area not yet drilled but judged as economically producible based upon available geologic and engineering data. Because of its conservative nature, the initial estimate of proved reserves based on a field's discovery well is generally significantly smaller than the quantity of gas ultimately recovered from the field. Wells drilled in subsequent years may increase the proved area of the reservoir or lead to the discovery of additional reservoirs within the field.

Each year, the sum of reserve additions attributed to the three types of exploratory wells are reported by the Energy Information Administration (EIA) as "new field discoveries" (these are the *initial*, first-year estimates of a new field's proved reserves), "extensions, " and "new reservoir (pool) discoveries in old fields. " (In this memorandum, this last category of reserve additions is called *new pool discoveries*, for brevity.) Another reporting category, "revisions," includes those reserves that are added or subtracted because of new information about old fields, for example, an indication that the fields will be drawn down to lower pressures because of a gas price increase, pressure histories during production that deviate from the expected values, or the use of measures to increase recovery. Another category, "Net of Corrections and Adjustments, " reports reserve changes from corrections of previous arithmetic or clerical errors, adjustments to previously reported gas production volumes, late reporting of reserve additions, and so forth. * Table 4 shows the changes in U.S. gas reserves from 1977 to 1981 as reported in the EIA yearly report, U.S. *Crude Oil, Natural Gas and Natural Gas Liquids Reserves—Annual Report.*

*EIA began its data series in 1977 The American Gas Association and American Petroleum Institute also published reserve statistics in basically the same format (without a "corrections and adjustments" category) from 1966 to 1979, and in a somewhat different format from 1947 to 1965

Table 4.— Estimated Total U.S. Proved Reserves of Natural Gas–1977-81

Year	Net of corrections & adjustments (1)	Revision Increases (2)	Revision decreases (3)	Extensions to old reservoirs (4)	New reservoir discoveries in old fields (5)	New field discoveries (6)	Total discoveries[a] (7)	Production (8)	Proved reserves[b] 12/31 (9)	Net change from prior year (10)
Natural gas[c]										
1976	—	—	—	—	—	—	—	—	***213,278***[e]	—
1977	***–20***[d]	13,691	15,296	8,129	3,301	3,173	14,603	18,843	207,413	– 5,865
1978	2,429	14,969	15,994	9,582	4,579	3,860	18,021	18,805	208,033	620
1979	–2,264	16,410	16,629	8,950	2,566	3,188	14,704	19,257	200,997	– 7,036
1980	1,201	16,972	15,923	9,357	2,577	2,539	14,473	18,699	199,021	– 1,976
1981	1,627	16,412	13,813	10,491	2,998	3,731	17,220	18,737	201,730	2,709

NOTE "Old" means discovered in a prior year "New" means discovered during the report year

[a]Column 4 + Column 5 + Column 6

[b]Prior year Column 9 + Column 1 + Column 2 Column 3 + Column 7 Column 8

[c]Billion cubic feet, 14.73 psia, 60 F

[d]Consists only of reported corrections only

[e]Based on following year data

SOURCE Energy Information Administration, U S Crude *Oil, Natural* Gas, *and Natural* Gas *Liquids Reserves— 1981 Annual Report*, DO E/EIA-0216 (81), August 1982

HOW IS NATURAL GAS PRODUCED?

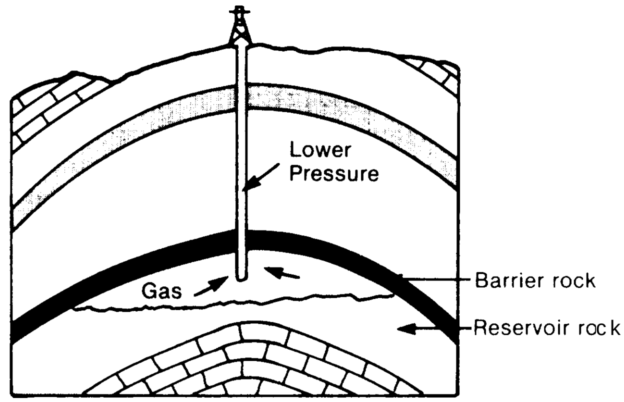
The way in which gas is produced depends on the properties of the reservoir rock and whether the gas occurs by itself or in association with oil. As illustrated in figure 7, hydrocarbons in the reservoir rock migrate to the producing well because of the pressure differential between the reservoir and the well. How readily this migration occurs is a function of the pressure of the reservoir and the permeability of the reservoir rock.

Production will continue as long as there is adequate pressure in the reservoir to propel the hydrocarbons toward the producing well. If gas is the only propellant, the reservoir pressure decreases as the gas is extracted and is eventually no longer sufficient to force the hydrocarbons toward the well. In a water-drive reservoir, water displaces the hydrocarbons from the pores of the reservoir rock, maintaining reservoir pressure during production and improving the recoverability of the hydrocarbons. In most reservoirs, gas recovery is high, generally greater than oil recovery. A "typical" recovery value of 80 percent is often cited, but the basis for this value is not firm, and recovery is certainly less in many reservoirs under current conditions. When gas occurs in association with oil, it can be reinfected into the reservoir to maintain pressure for maximum oil recovery. Gas is also reinfected when there are no pipeline facilities available to transport it to market.

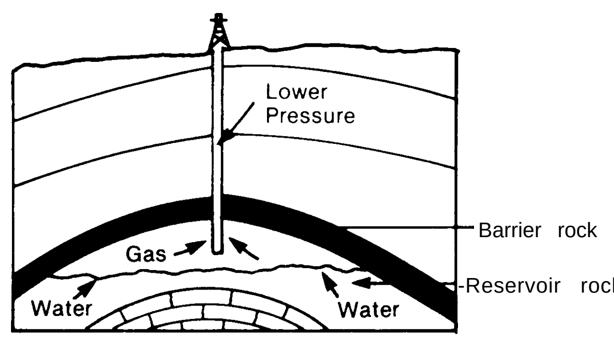
Once the raw gas is produced from the well, it is gathered with production from other nearby wells and processed to remove natural gas liquids and impurities that could cause problems in the pipeline. The gas is then sent by pipeline to local gas utilities who sell it to the end-user. In some instances, such as those involving large industrial users, the pipeline will sell directly to the end-user and bypass the local gas utility.

Figure 7.— Production Mechanics

Gas drive mechanism



Gas and water drive mechanism



SOURCE Office of Technology Assessment