Chapter 8

Natural Gas

Chapter Objectives:

1. Describe natural gas consumption trends in the U.S. and the world.
2. Describe natural gas production trends in the U.S. and the world.
3. Discuss problems with natural gas usage.
4. Describe the potential benefits and problems with natural gas shale.
5. Describe the potential benefits and problems with coal bed methane.
6. Describe the current knowledge about methane hydrates.

History

In the world of fossil fuels, natural gas is often the overlooked ugly duckling. It gets lumped in with oil, as in "oil and gas industry," even though the discussion usually centers upon oil. It does not help that gasoline, which is derived from oil, is shortened to "gas." In many people's mind, the "gas" in "oil and gas" refers to gasoline, and not natural gas.

However, natural gas has much to offer as an energy source that makes it preferable to other forms of fossil fuels. It burns much cleaner than coal or oil, and it produces far less carbon dioxide for each unit of energy. Its simple chemical nature makes it a much better source to use in high efficiency fuel cells than either coal or gas. As a usable energy source, natural gas really has only one stumbling block, but it is a major one: it is hard to transport and store. If the transport or storage system is not completely sealed, natural gas will leak. Further, both systems must be able to withstand high pressures in order to compact the natural gas into a reasonable space.

Fig. 1: a liquid natural gas storage tank

These problems have kept natural gas from widespread usage throughout history, even though its existence has been known about for a long time. Like coal and oil, natural gas has been used for several millennia. The earliest records of this date back to 200 B.C., when the Chinese developed a crude system of bamboo pipes to transport gas to burners to evaporate brine to make salt[1]. However, it was not until large-scale pipe systems were developed in the 1800's that natural gas began to see extended use. Initially, it was used for lighting in homes and buildings. The increased production of electricity in the late 1800's led to a decline in this usage, although there became a growing demand throughout the 1900's for its use to heat homes, water, and cook.

Usage of natural gas remained near its source of production until long-range pipelines or transport was created. In 1925, the first all-welded pipeline over 200 miles in length was built, running from Louisiana to Texas. The growth in such pipeline networks and the cheap price of natural gas led to an expansion in its use. Between the turn of the century and 1970, usage and production of natural gas increased fifty-fold. After a peak in 1973, the production of natural gas in the U.S. remained fairly flat until the price, demand, and new technology converged to increase production somewhat dramatically in the last 5 years (see below).

Usage

Over the last century, the use of natural gas has become more diversified. In 2013, 26.1 trillion cubic feet of natural gas were used in the U.S. Table 1 (below) shows a list of the different uses of this amount of natural gas. As you can see, natural gas has come a long way from being used primarily to provide lighting, and it is still evolving rapidly. The greatest use today is in the electricity generation sector, but that was not true just a decade ago. Electricity generation from natural gas has increased by 57% since 2000. This growth is due to the fact that it burns cleaner and can generate electricity more efficiently than can coal, as new turbine generators use their exhaust to boil water, improving efficiency up to 50-60%. The second greatest sector for use is industry, where natural gas is used as a heat source and as a chemical feedstock for such things as fertilizer. Most of the remaining natural gas is used for heating, hot water, and cooking in homes and companies.

TABLE 1: U.S. NATURAL GAS CONSUMPTION[2]

USE	PERCENT
residential	18.9
commercial	12.9
industrial	28.5
electricity generation	30.4
automobiles	0.1
pipeline	3.3
lease and plant	5.8

Table 1 also shows a few other uses of natural gas. A very small portion of the total amount is used in cars and trucks as an alternative fuel to gasoline. This usage results in reduced emissions from automobiles. However, the sparse usage for this (about 0.1%) means that it makes a very small dent in the amount of air pollution. The remaining 8.9% is used to extract the natural gas, remove condensates and such, and push it through the pipelines. This wasted energy lowers the overall efficiency of natural gas. While it is a decent amount of energy to waste, it is still far lower than the amount of energy that is wasted in both the oil and coal sectors for refining and transportation.

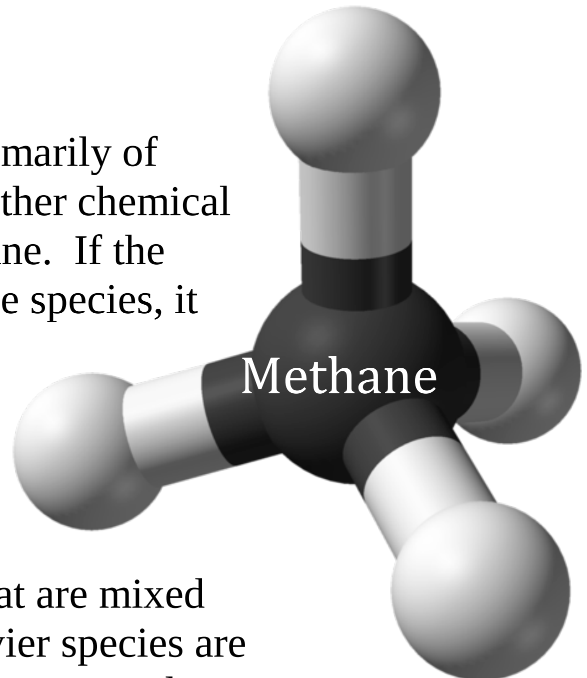
The U.S. is the world's largest consumer of natural gas, due in mostly to our large supplies and our ample pipeline network for getting the gas to market. Many countries do not have a delivery system, which severely limits its usage there and often results in natural gas from wells there being burned at the wellhead. Still, natural gas is the third largest commercial fuel source worldwide, accounting for 23 percent of global energy consumption. In 2013, there was a total of 120 trillion cubic feet of it consumed. Table 2 shows the top five consumer countries of natural gas. As you can see, the U.S. and Russia use much more natural gas than any other

TABLE 2: WORLDWIDE USAGE (2013)[3]

COUNTRY	USAGE (TCF)
U.S.	26.1
Russia	14.6
Iran	5.5
China	5.2
Japan	4.6

country. Iran, China, and Japan, though, have been increasing their usage at an incredible pace. Since 2000, all have more than doubled the amount that they consume. China is on the steeper consumer curve, and should pass Iran within the next several years.

Creation



Natural gas is composed primarily of methane (CH_4). It does contain other chemical species, such as butane and propane. If the mixture is comprised only of these species, it is called dry natural gas, as there will be no liquid components at standard pressure and temperature. There might also be some other organic components, such as pentanes, that are mixed in with these species. These heavier species are normally liquid at standard temperature and pressure, and comprise what is called natural gas liquids. Natural gas might also be mixed in with non-hydrocarbon compounds, such as water vapor, carbon dioxide, and hydrogen sulfide. If so, it forms what is called wet natural gas, and requires some processing before it can be used.

Natural gas comes from the decomposition of organic matter, just like oil and coal. Unlike oil and coal, though, it can come from almost any organic matter, whereas coal comes only from plant matter and oil comes almost exclusively from plankton and microplankton remains. Natural gas can come from both of these sources as well. This is why you often find it associated with both oil wells and coal mines.

Natural gas can also come from unconventional sources, as well. It is produced by dead plant matter decay in swamps and rice fields. Animals, such as cattle and termites, produce large quantities as a by-product of digestion. These sources, though, cannot be tapped for energy use. Other unconventional sources, such as landfills, manure digesters, and wastewater treatment plants, are used to produce natural gas. China produces enough gas from manure digesters to provide cooking and lighting for over 6 million homes. In the U.S., we have over 636 landfill gas projects that can produce almost 2,000 MW of electrical power.[4] These unconventional sources fall under the heading of renewable sources of energy, as they are using waste products that will continue to be produced. Conventional sources, unfortunately, are not renewable, as the rate of their production far exceeds the rate at which they are being produced.

Fig. 2: Jefferson County landfill (DOE)

Production and Reserves

The production of natural gas has changed as price, demand, and technology have changed over the years. After a rapid increase throughout the 1950's and 1960's spurred by new pipelines and uses for cooking and heating, the production of natural gas appeared to have peaked in the U.S. in 1973. In that year, over 22 trillion cubic feet of natural gas were produced from wells throughout the U.S., almost all of which were in the lower 48 states. Production fell off during the late 1970's and early 1980's as pipeline production ceased and prices fell (decreased demand for new wells), reaching a low of 16 trillion cubic feet in 1986. A continued decrease in price helped to spur increased demand for natural gas as electricity producers began to use it because of the possible greater efficiency in power plants. This caused an increase in production, but only to the point that conventional wells were able to produce. With the development of horizontal wells and hydrofracturing of shale deposits, production has taken off over the last decade, leading to all-time highs in domestic production.

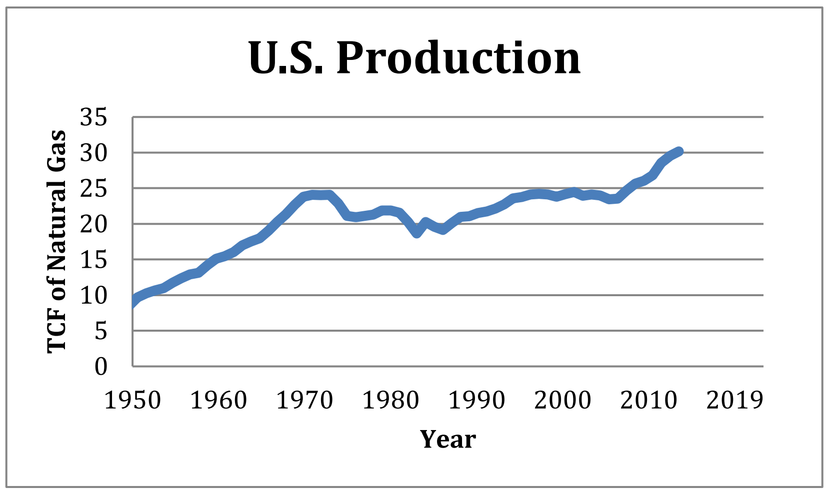


Fig. 3: U.S. production of natural gas

The majority of natural gas production in the U.S. comes from Texas (7.5 TCF), Pennsylvania (3.3 TCF), Louisiana (2.4 TCF), Oklahoma (2.1 TCF), Wyoming (1.9 TCF), Colorado (1.6 TCF), and the federal waters in the Gulf of Mexico (1.3 TCF). Together, they account for about three-fourths of the total production in the U.S.[5]. More accurately, we really should clarify this and say that these are the largest producers that send natural gas to market. Almost 3 trillion cubic feet of natural gas are withdrawn from wells in Alaska. However, because of the lack of an available pipeline to handle shipping this much natural gas from the North Slope region, the natural gas is pumped back into the ground for storage. While pipelines have been proposed to ship the natural gas down to the lower 48 states, the cost of such a venture has made the probability of this becoming a reality any time soon zero.

These production ratios between the various states closely matches the ratio of proven reserves of natural gas. By most estimates, the U.S. has over 600 trillion cubic feet of natural gas in proven reserves. Of this, almost a third (188 TCF) is in the state of Texas or in the federal waters offshore of it, while another 60 TCF is in Louisiana or in the federal waters offshore of it. Along with these two regions come Wyoming (71 TCF), New Mexico (32 TCF), Oklahoma (55 TCF), and Colorado (49 TCF) in proven reserves. This accounts for about three-fourths of the proved reserves between these six states. These ratios of production and reserves also account for why most of the natural gas consumption in the U.S. occurs in the South and West.

As we stated previously, the worldwide consumption of natural gas is about 147 TCF a year. The largest producing country is the U.S. (29.8 TCF) followed by Russia (23.0 TCF). This situation has changed from just eight years ago, when Russia was the number one producer. These two alone produce over 30% of the world's output. After them, production values for other countries fall off quickly. Iran is the world's third largest producing country with 8.2 TCF per year, while Algeria and Canada are close behind with 6.4 and 6.3 TCF per year, respectively[6].

As noted above, Iran has dramatically increased its production over the last several years. The reason for this is simple: they have one of the largest reserves of natural gas in the world. While Russia leads the world with reserves of about 1,700 TCF, Iran (1054 TCF) and Qatar (899 TCF) are not that far behind. Their total reserves outstrip the sums of the U.S. (over 600 TCF) and Canada (60 TCF)[7]. As we said before, the lack of an infrastructure that can get the natural gas from the wellhead to market makes the availability of this energy supply to consumers impossible in many countries. As that infrastructure is built, though, we can see that it can readily be put to use. Until it is built, though, it can create waste, as more than 3 TCF of natural gas a year are vented or flared into the atmosphere each year.

Shale Gas: Horizontal Drilling and Fracturing

As Figure 3 shows, the production of natural gas in the U.S. had remained stagnant or declined for 30 years after peaking in 1973. Over the last decade, this trend has reversed, as the amount of natural gas produced in the U.S. has increased by about 22% at the same time as proven reserves have increased. One of the reasons for this turnaround is the production of formerly uneconomic plays of natural gas located in rock formations with low permeability such as shale. These deposits have been made economical by the employment of a combination of horizontal drilling and hydraulic fracturing (Video).

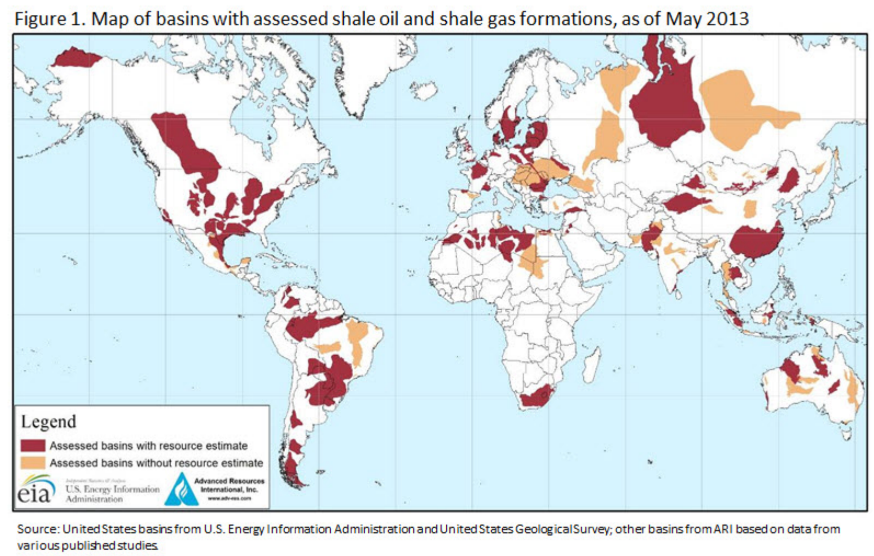
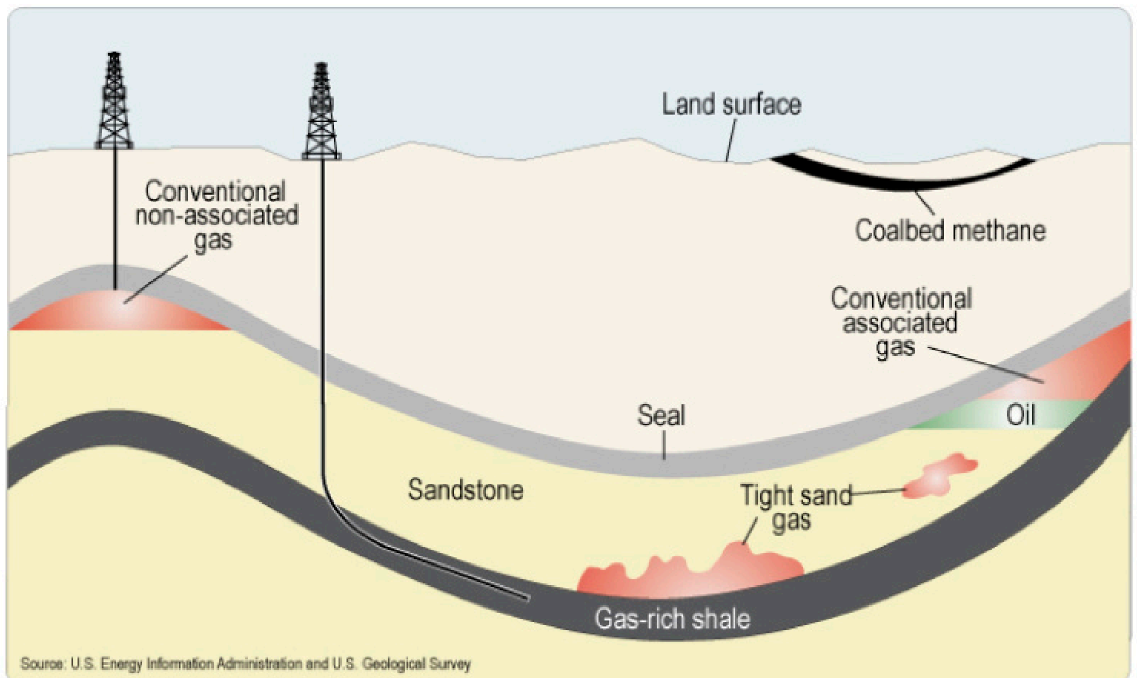


Fig. 4: map of shale gas basins of the world

Horizontal drilling is accomplished using a steerable drill bit that is attached to the end of a pipe that can be expanded in length by adding new sections to it. The drill bit initially goes vertically into the ground until it passes below the near-surface water table.

At this point, the drill is pulled out and the space between the rock and pipe are filled with cement in an effort to seal off the water from the hydrocarbons that will come out later. After the pipe is set, the drill continues to run vertically until it reaches a depth of about 500 feet above the intended reservoir. Then the bit is steered in a gentle curve that will eventually leave the pipe running in a mostly horizontal direction along the reservoir until it reaches its endpoint. The drill is then removed again, and cement is poured between the pipe and the rock to hold it in place and prevent a blowout.



After the well is set, the process of hydraulic fracturing begins in order to open up cracks in the low permeability shale to allow the natural gas to flow from the rock into the pipe. A fracturing gun is placed into the pipe segments. When an electrical signal is sent to the gun, projectiles are exploded through the pipe and cement into the rock. The segment is then sealed off and pressurized with water and chemicals that cause the holes to widen and fracture. After completion of a single segment, the process begins on the next segment until the inter length of the reservoir is completed. At this point, the plugs are removed from the line, opening the well up to the natural gas from the reservoir.

These two methods have greatly enhanced the amount of natural gas that can be recovered by increasing the permeability of the rock while also increasing the length of the well in contact with the reservoir. We currently recover over 5 TCF of natural gas by this method, and our production has been increasing at over 1 TCF per year for the last several years. The major production so far has come from Texas, Louisiana, Pennsylvania, Oklahoma, and Arkansas, but it is expected that production will increase in other states such as Wyoming and South Dakota as time goes by.

There is some concern that this method is negatively impacting the water table in many locations and causing mini earthquakes. Recent reports of flammable liquids coming out of people's water wells would seem to indicate that the wells are either not sealing themselves as well as they should or that the fracturing is greater than what was previously thought. Series of low magnitude earthquakes in regions of hydrofracturing could mean that the process is unsettling old static zones in the plates. While there has been a call for more studies, there does not appear to be any slow down in production by this method.

Coal Bed Methane

This picture of the world's supply of natural gas can be radically altered by two fairly new potential sources of natural gas: coal bed methane and methane hydrates. Coal bed methane is exactly what it sounds like: it is natural gas that is trapped within coal seams. The natural gas (mostly methane) got there during the coal creation process as some of the plant matter was broken down by pressure, heat, and bacteria.

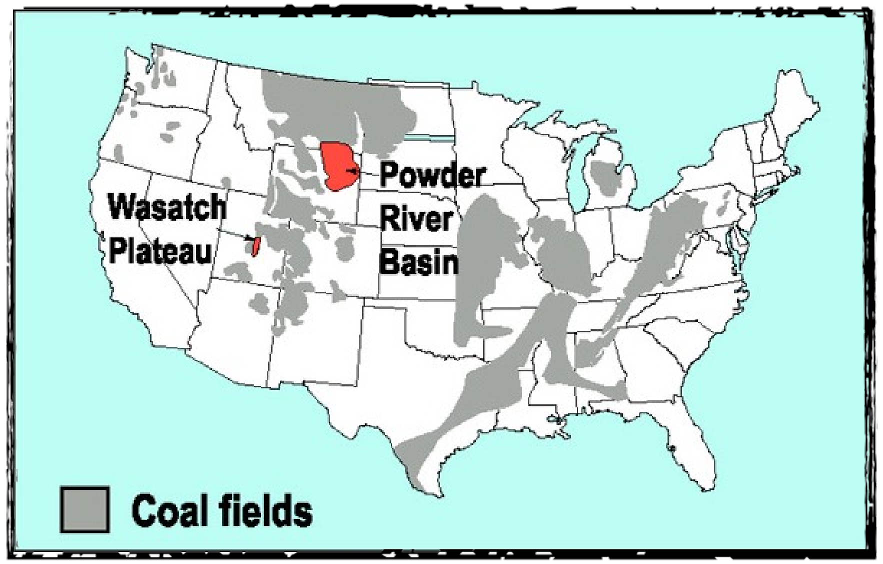


Fig. 5: current coal bed methane production

Unlike some deposits of natural gas in Colorado and Wyoming, this methane did not migrate from the coal seam to become lodged in sedimentary rocks nearby. Due to the large amount of surface area inside the coal that can trap the gas, the coal seam can store up to six or seven times what a conventional rock formation will hold. This means that these formations could produce vast quantities of natural gas. It is estimated that there is about 700 TCF of coal bed methane in the U.S., with about 100 TCF of this being recoverable with today's technology (so far, there is only about 18.5 proved reserves of coal bed methane)[8]. This could double our reserves of natural gas.

Besides the potential increase in reserves, coal bed methane has a few other characteristics that makes it desirable. Natural gas that is associated with petroleum reserves is usually found at depths that are about 1-4 miles deep within the Earth. This means that drilling to get to these reserves is very costly. Furthermore, the pressures found at these depths means that pore spaces within the rocks is usually very tight, causing low permeability in the rock and harming production. Coal bed methane, on the other hand, is usually found at very shallow depths of anywhere from a couple of hundred feet to maybe a mile. This greatly reduces the price of drilling. The lower pressure at these depths means that natural gas can more readily flow from the coal, which increases production and further reduces costs.

Coal bed methane does have some problems, especially when one considers the effect on the environment. Most shallow coal beds still contain a large amount of water. This water tends to block the pore spaces in the coal and decreases flow rates of natural gas to the well. One way to increase the flow rate is to draw off the water, and thereby open up the pathways for natural gas to flow. This produced water is often saline in nature, which makes its disposal problematic. Allowing the water to runoff on the surface will increase the salinity of local water ecosystems, and radically affect the local plant and wildlife population. Injecting the water back into the ground increases expenses, which decreases the profitability of the wells. Either way, the drawing off of the water will lower the local groundwater, which can have affects on local communities.

Our knowledge of extraction of natural gas from coal beds is still in its infancy. We currently produce about 1.9 TCF of methane this way, but it could be much more if it was widely used. Much more research is needed to properly understand the particulars of this situation.

Methane Hydrates

Another potentially large source of natural gas is methane hydrate formations. These are solid, crystalline features that are composed of a combination of methane, water ice, and other gases. The methane and gases are trapped in the lattice structure of the water ice, which, like coal beds, can hold much more natural gas than normal rock features. These hydrate formations are usually found on the ocean floor where there is high pressure and near freezing temperatures. This usually requires water depths greater than 300 feet.

Knowledge about these structures is quite slim. For one thing, we are not sure how they form. It could be that the methane is produced by bacteria near the seafloor that are decomposing organic sediments. However, it might also be that the methane originates from oil deposits deep within the Earth that leaks to the sea floor bottom through faults and cracks. Either way, it is still unknown how the methane gets trapped within an ice lattice. The lack of this knowledge means that we have no idea what conditions would be favorable for their formation. This limits our ability to search for such structures.

Another matter that is unknown about methane hydrates is their stability. The ice lattice structure is fairly delicate, being much more fragile than a sedimentary rock would be that contains natural gas. If the hydrates should breakdown, it would cause a massive release of methane into the atmosphere. By some estimates, there is 3,000 times the amount of methane in hydrate formations than is found in the atmosphere currently. Given the size of these deposits and the ability of methane to absorb infrared radiation, this could increase the greenhouse effect dramatically. Further, the decay of these hydrates on the ocean bottom could cause massive landslides, which would cause problems for any extraction facility built nearby. This lack of knowledge about the stability of the hydrate formations prevents us from building any type of extraction facility at this time.

Lastly, we have no idea how much methane hydrate there is in the world. The USGS estimates that there is twice the amount of carbon to be found in methane hydrate deposits as there is in all other fossil fuels combined. However, this estimate is made with scant information, and could very well be wild speculation. There is better data for the existence of methane hydrates in certain locations. Mappings by the USGS of offshore North and South Carolina reveal the possible existence of a 1,300 TCF methane hydrate deposit. If this is true, and if it could be extracted safely, it would represent a 700% increase in the current natural gas deposits in the U.S. At current consumption rates, this would be a 70-year reserve of natural gas[9].

While the potential for methane hydrates as an energy source are quite high, our current lack of knowledge about their properties limits our ability to pursue. Much more research is required before we attempt to exploit them as a source.

Discussion Questions

1. How much natural gas does the U.S. have in proved reserves? At our current rate of consumption, how long should this last?

2. What are the potential problems with the production of coal bed methane? With methane hydrates? With natural gas shale?

3. In what ways is natural gas a superior energy source to oil and coal? In what ways is it inferior?

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7. http://www.eia.doe.gov/emeu/iea/table81.html, October 10, 2010.

8. “Coal Bed Methane: Potential and Concerns”, USGS Fact Sheet FS-123-00, October 2000.

9. http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html, January 10, 2004.

Additional Readings

The following link discusses research on methane hydrates. The site is maintained by the Department of Energy and also contains links to additional resources.

Department of Energy

Topic: National Methane Hydrate Program

Summary: Contains information about methane hydrate research.

Link: http://www.netl.doe.gov/research/oil-and-gas/methane-hydrates

The following Department of Energy website is a clearinghouse for information about natural gas.

Department of Energy

Topic: Natural Gas Information Navigator

Summary: Clearinghouse for information about natural gas.

Link: http://www.eia.gov/naturalgas/index.cfm

The following is an opinion piece on the state of natural gas in the world. It provides background information, as well as projections for what the future holds.