ESA21
Environmental Science Activities for the 21st Century

Fossil Fuels: Natural Gas

Introduction

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.

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.

Most of this usage of natural gas was near the wells that produced it due to the lack of long-range pipelines or transport. 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. However, production of natural gas in the U.S. peaked in 1973, and by 1980, we began to import natural gas from other countries. Today, about 15 percent of our natural gas comes from other countries, mostly through pipelines from Canada[1].

Usage

Over the last century, the use of natural gas has become more diversified. In 2002, 22.6 trillion cubic feet of natural gas were used in the U.S. Table 1 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. The greatest use today is in the industrial sector as an energy source and as a chemical feedstock for such things as fertilizer. The second greatest use is for generating electricity. This is a growing sector, as the creation of new turbine generators that burn the gas in an engine and then use the exhaust to boil water results in power plant efficiencies of 50-60%. Most of the remaining natural gas is used for heating, hot water, and cooking in homes and companies.

Use	Percent
Residential	21.7
Commercial	14.0
Industrial	31.8
Electricity Generation	25.0
Automobiles	.1
Pipeline	2.8
Lease and plant	4.6

Table 1: U.S. Natural Gas Consumption[2]

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 (less than .1%) means that it makes a very small dent in the amount of air pollution. The remaining 7.4% 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.

Country	Usage (TCF)
U.S.	22.6
Russia	14.4
Germany	3.3
United Kingdom	3.3
Canada	2.9

Table 2: Worldwide Usage (2002)[3]

The U.S. is the world's largest consumer of natural gas, due in large part 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 2002, there was a total of 90.3 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 country.

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 coalmines.

Fig. 1: Jefferson County Landfill (DOE)

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 340 landfill gas projects that can produce over 1,000 MW of electrical power. 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.

Production and Reserves

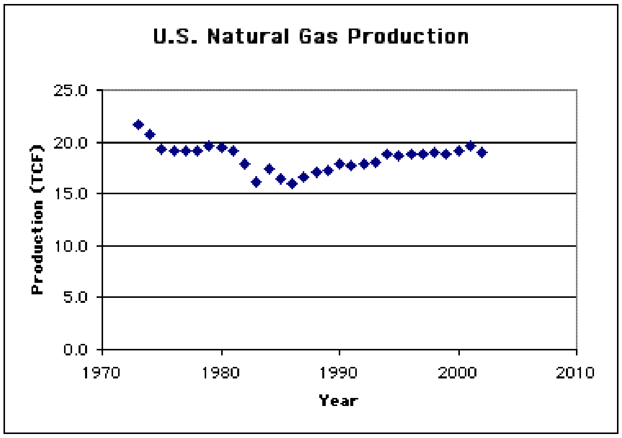

Fig. 2: U.S. production of natural gas

The production of natural gas peaked in the U.S. in 1973. In that year, over 22 trillion cubic feet of natural gas were produced from wells, almost all of which were in the lower 48 states. Production fell off rapidly in the late 1970's and reached a low of 16 trillion cubic feet in 1986. Soon after this low was reached, the price of natural gas began to fall, being cut in half within four years. This low price helped to spur increased demand for the natural gas, which experienced a steady increase in production throughout the 1990's. U.S. production has been leveling off in recent years, with the increase in demand being met by importing natural gas from Canada and a few other countries.

The majority of natural gas production in the U.S. comes from Texas (5.0 TCF), Louisiana (1.3 TCF), and the federal waters offshore of these two states (4.4 TCF). Together, they account for over 10 trillion cubic feet of natural gas, which is more than half of the 19.3 trillion cubic feet produced in 2002. Behind these two regions, the largest production comes from New Mexico (1.5 TCF), Oklahoma (1.5 TCF), and Wyoming (1.4 TCF)[4]. More accurately, we really should clarify this and say that these are the largest producers that send natural gas to market. Over 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 between 180 to 190 trillion cubic feet of natural gas in proved reserves. Of this, about one quarter (50 TCF) is in the state of Texas or in the federal waters offshore of it, while another 28 TCF is in Louisiana or in the federal waters offshore of it. Behind these two regions come Wyoming (20 TCF), New Mexico (17 TCF), Oklahoma (15 TCF), and Colorado (14 TCF). 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 a little over 90 TCF a year. The largest producing country is Russia (21 TCF), followed quickly by the U.S. (19 TCF). These two alone produce almost half of the world's output. After them, production values for other countries fall off quickly. Canada is the world's third largest producing country with 6.5 TCF per year, while the United Kingdom is fourth with 3.8 TCF per year[5].

What is interesting is that these are not all of the countries with the largest proven reserves of natural gas. Russia leads the world with reserves of about 1,700 TCF. However, Iran (940 TCF) and Qatar (760 TCF) have reserves that far outstrip the sums of the U.S. and Canada (60 TCF)[6]. 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. It is this lack of infrastructure that causes more than 3 TCF of natural gas a year to be vented or flared into the atmosphere.

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. 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)[7,4]. This would increase our reserves of natural gas by over 60%.

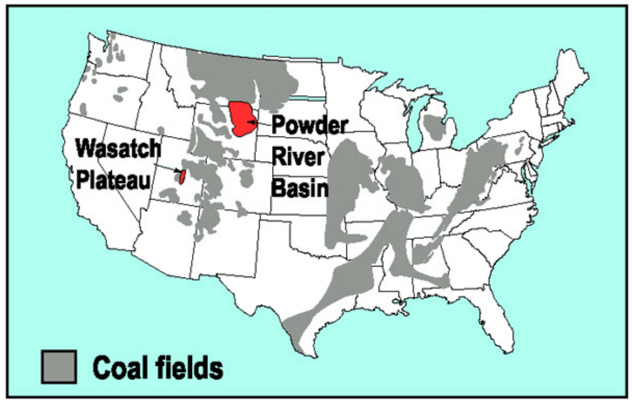

Fig. 3: Current coal bed methane production[7]

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.

Currently, our knowledge of extraction of natural gas from coal beds is still in its infancy. We do not understand how best to produce natural gas from these areas, nor do we know what environmental damage will be done by doing so. Much more research is needed to properly understand the particulars of this situation. Unfortunately, there are many forces that are pushing the extraction from coal beds right now, which could cause huge problems in the near future.

Methane Hydrates

Fig. : Diagram of methane in ice lattice

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[8].

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.

Additional Reading

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/scng/hydrate/

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://tonto.eia.doe.gov/dnav/ng/ng_sum_top.asp

Activity

This week's activity will investigate the concepts of porosity and permeability. Porosity refers to the percentage of the volume of a rock that is interstitial or open to be filled with a fluid substance. Permeability is the measure of how well the pore spaces in a rock are connected. A reservoir that contains a lot of oil in a small volume is going to consist of rock that is fairly porous. In order to get the oil out of the rock, though, these pore spaces need to be very well connected so that the rock is permeable. We will investigate what type of factors affect these two properties.

We will first consider porosity. We are going to investigate how the shape of the sediments in the sedimentary rock affects the porosity. This will be done with the aid of sediment analogs, as trying to pump fluids into real sedimentary rocks can be quite difficult. For sediment analogs, we will use metal bearings and high-density polyethylene bags to mimic sand and clay. The polyethylene bags will need to be cut or shredded into thin, rectangular pieces that will lie flat. You will also need a graduated cylinder, three medium-sized beakers (around 400 mL), and water. The procedure for this portion of the activity is easy.

1. Fill each beaker to about the line nearest the midpoint with the "sediments" listed above. Record the quantity on the activity sheet.
2. Fill the graduated cylinder to with water and note how much water is in it.
3. Pour the water slowly into the beaker with bearings until the water just reaches the top of the bearings. If you need run out of water in the cylinder, fill it again, and note the added amount. Be sure to slightly agitate the beaker to make sure that no large air bubbles are trapped by the bearings. Record how much water is left in the cylinder, and calculate the amount added by subtracting the amount left from the initial amount. Record this quantity on the activity sheet
4. Repeat the above step with the other two beakers.
5. Answer the questions on the activity sheet.

In the second portion of this activity, we are going to investigate permeability using different sediment samples. For this portion, you will need a bucket or large pan each of sand, silt, and clay, as well as a metal or glass tube of an inch diameter or more, a stopwatch, a graduated cylinder, and water. The procedure to follow is

1. Pack the different sediments into the buckets or pans. Make sure to press down hard to insure that the grains of sediment are well seated. You might wish to dampen the sediments beforehand to make sure that they will stick together.
2. Push the tube into the sediment an inch or more, making sure that the tube is an inch or more from the bottom of the container.
3. Fill the graduated cylinder with water.
4. Begin to pour the water into the tube at the same time that you start the stopwatch. Keep pouring the water into the tube until all of it is out of the graduated cylinder. When the water has all absorbed into the sediment in the tube, turn off the stopwatch and record the time.
5. Repeat this procedure 3 times with each sediment, making sure to drain off the water from the sediment after each run. Alternatively, you can put small holes in the bottom of your bucket/pan and allow the water to drain out that way.
6. Answer the questions on the activity sheet.

References

1 http://www.eia.doe.gov/kids/milestones/naturalgas.html, January 10, 2004.
2 http://tonto.eia.doe.gov/dnav/ng/xls/ng_cons_sum_nus_m_d.xls, January 10, 2004.
3 http://www.eia.doe.gov/emeu/iea/table13.html, January 10, 2004.
4 "U.S. Crude Oil, Natural Gas, and Natural Gas Liquids Reserves 2002 Annual Report", Department of Energy, Energy Information Administration, 2002.
5 http://www.eia.doe.gov/emeu/iea/table41.html, January 10, 2004.
6 http://www.eia.doe.gov/emeu/iea/table81.html, January 10, 2004.
7 "Coal Bed Methane: Potential and Concerns", USGS Fact Sheet FS-123-00, October 2000.
8 http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html, January 10, 2004.

ESA21: Environmental Science Activities

Activity Sheet
Porosity and Permeability

Name:

Material	Amount of material (mL)	Water Added	Porosity
Bearings			
Plastic			

1. Which material had the larger porosity? Why?

2. What sedimentary rock would be most like your larger porosity analog above?

Sediment	Water Amount	Time 1	Time 2	Time 3	Average Time	Flow Rate
Clay						
Silt						
Sand						

3. Which sediment had the best flow rate? Why do you think this was so?

4. Given your answers in both sections, what type of rock do you think would be the best for a reservoir: a claystone, a siltstone, or a sandstone?