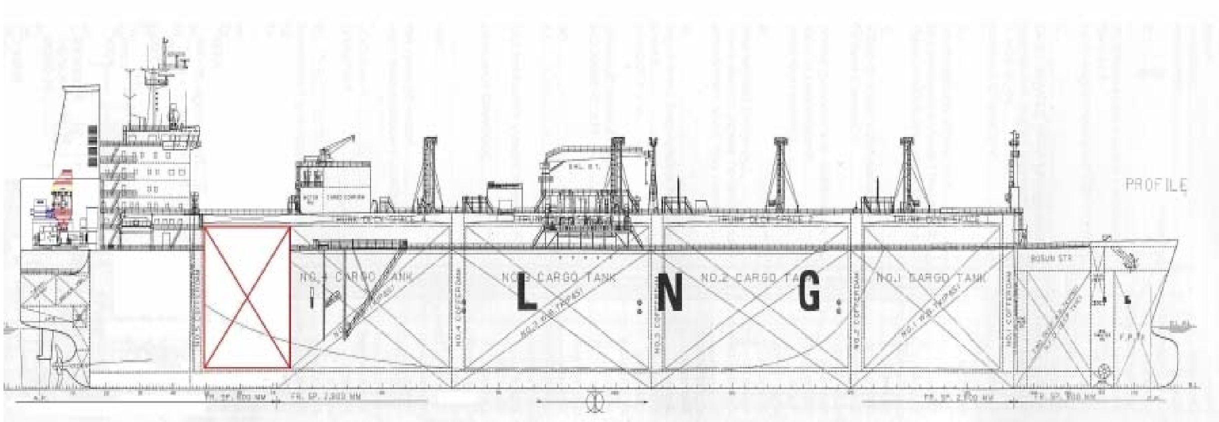

FUTURE OF LNG TRANSPORTATION:VARIOUS PROPULSION ALTERNATIVES

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CHAPTER: 1

LIQUIFIED NATURAL GAS

1.1 Introduction

Natural Gas is a vital component of the world's supply of energy. It is one of the cleanest, safest, and most useful of all energy sources. Despite its importance, however, there are many misconceptions about natural gas. For instance, the word 'gas' itself has a variety of different uses, and meanings. When we fuel our car, we put 'gas' in it. However, the gasoline that goes into your vehicle, while a fossil fuel itself, is very different from natural gas. The 'gas' in the common barbecue is actually propane, which, while closely associated and commonly found in natural gas, is not really natural gas itself. While commonly grouped in with other fossil fuels and sources of energy, there are many characteristics of natural gas that make it unique. Below is a bit of background information about natural gas, what exactly it is, how it is formed, and how it is found in nature.

A Natural Gas Wellhead
Source: Duke Energy Gas Transmission Canada

Source: NGSA

1.1.1 What is Natural Gas?

Natural gas, in itself, might be considered a very uninteresting gas - it is colorless, shapeless, and odorless in its pure form. Quite uninteresting - except that natural gas is combustible, and when burned it gives off a great deal of energy. Unlike other fossil fuels, however, natural gas is clean burning and emits lower levels of potentially harmful byproducts into the air. We require energy constantly, to heat our homes, cook our food, and generate our electricity. It is this need for energy that has elevated natural gas to such a level of importance in our society, and in our lives.

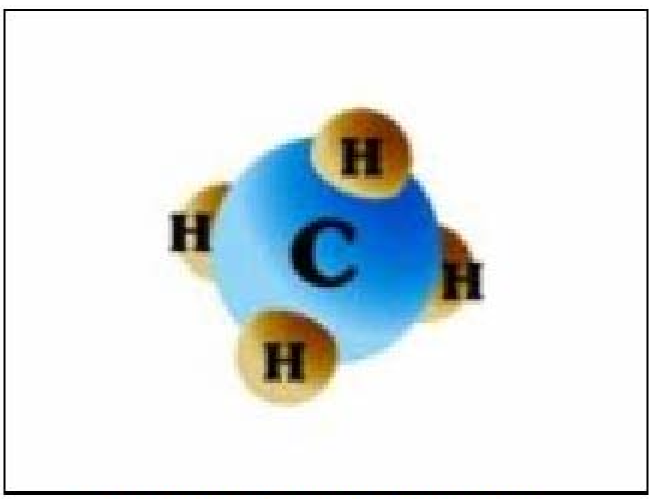
Natural gas is a combustible mixture of hydrocarbon gases. While natural gas is formed primarily of methane, it can also include ethane, propane, butane and pentane. The composition of natural gas can vary widely, but below is a chart outlining the typical makeup of natural gas before it is refined.

Typical Composition of Natural Gas

Methane	CH_4	70-90%
Ethane	C_2H_6	0-20%
Propane	C_3H_8	
Butane	C_4H_{10}	
Carbon Dioxide	CO_2	0-8%
Oxygen	O_2	0-0.2%
Nitrogen	N_2	0-5%
Hydrogen sulphide	H_2S	0-5%
Rare gases	A, He, Ne, Xe	trace

In its purest form, such as the natural gas that is delivered to your home, it is almost pure methane. Methane is a molecule made up of one carbon atom and four hydrogen atoms, and is referred to as CH4.

Ethane, propane, and the other hydrocarbons commonly associated with natural gas have slightly different chemical formulas, which can be seen here.



A Methane molecule, CH_4

Source: USGS

Natural gas is considered 'dry' when it is almost pure methane, having had most of the other commonly associated hydrocarbons removed. When other hydrocarbons are present, the natural gas is 'wet'.

Found in reservoirs underneath the earth, natural gas is commonly associated with oil deposits. Production companies search for evidence of these reservoirs by using sophisticated technology that helps to find the location of the natural gas, and drill wells in the earth where it is likely to be found. Once brought from underground, the natural gas is refined to remove impurities like water, other gases, sand, and other compounds. Some hydrocarbons are removed and sold separately, including propane and butane. Other impurities are also removed, like hydrogen sulfide (the refining of which can produce sulfur, which is then also sold separately). After refining, the clean natural gas is transmitted through a network of pipelines, thousands of miles of which exist in the United States alone. From these pipelines, natural gas is delivered to its point of use.

Natural gas can be measured in a number of different ways. As a gas, it can be measured by the volume it takes up at normal temperatures and pressures, commonly expressed in cubic feet. Production and distribution companies commonly measure natural gas in thousands of cubic feet (Mcf), millions of cubic feet (MMcf), or trillions of cubic feet (Tcf). While measuring by volume is useful, natural gas can also be measured as a source of energy. Like other forms of energy, natural gas is commonly measured and expressed in British thermal units (Btu). One Btu is the amount of natural gas that will produce enough energy to heat one pound of water by one degree at normal pressure. To give an idea, one cubic foot of natural gas contains about 1,027 Btus. When natural gas is delivered to a residence, it is measured by the gas utility in 'therms' for billing purposes. A therm is equivalent to 100,000 Btu's, or just over 97 cubic feet, of natural gas.

1.2 The Formation of Natural Gas

Natural gas is a fossil fuel. Like oil and coal, this means that it is, essentially, the remains of plants and animals and microorganisms that lived millions and millions of years ago. But how do these once living organisms become an inanimate mixture of gases?

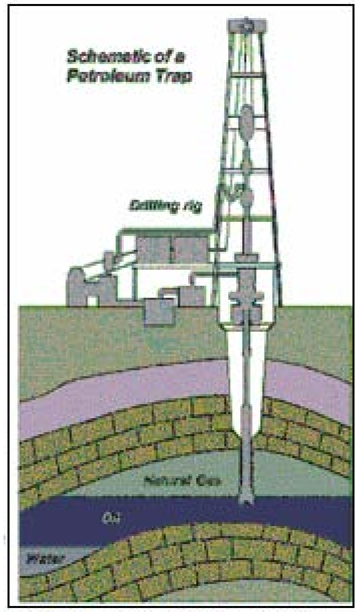
There are many different theories as to the origins of fossil fuels. The most widely accepted theory says that fossil fuels are formed when organic matter (such as the remains of a plant or animal) is compressed under the earth, at very high pressure for a very long time. This is referred to as thermogenic methane. Similar to the formation of oil, thermogenic methane is formed from organic particles that are covered in mud and other sediment. Over time, more and more sediment and mud and other debris are piled on top of the organic matter. This sediment and debris puts a great deal of pressure on the organic matter, which compresses it. This compression, combined with high temperatures found deep underneath the earth, break down the carbon bonds in the organic matter. As one gets deeper and deeper under the earths crust, the temperature gets higher and higher. At low temperatures (shallower deposits), more oil is produced relative to natural gas. At higher temperatures, however, more natural gas is created, as opposed to oil. That is why natural gas is usually associated with oil in deposits that are 1 to 2 miles below the earth's crust. Deeper deposits, very far underground, usually contain primarily natural gas, and in many cases, pure methane.

Natural gas can also be formed through the transformation of organic matter by tiny microorganisms. This type of methane is referred to as biogenic methane. Methanogens, tiny methane producing microorganisms, chemically break down organic matter to produce methane. These microorganisms are commonly found in areas near the surface of the earth that are void of oxygen. These microorganisms also live in the intestines of most animals, including humans. Formation of methane in this manner usually takes place close to the surface of the earth, and the methane produced is usually lost into the atmosphere. In certain circumstances, however, this methane can be trapped underground, recoverable as natural gas. An example of biogenic methane is landfill gas. Waste-containing landfills produce a relatively large amount of natural gas, from the decomposition of the waste materials that they contain. New technologies are allowing this gas to be harvested and used to add to the supply of natural gas.

A third way in which methane (and natural gas) may be formed is through a biogenic process. Extremely deep under the earth's crust, there exist hydrogen-rich gases and carbon molecules. As these gases gradually rise towards the surface of the earth, they may interact with minerals that also exist underground, in the absence of oxygen. This interaction may result in a reaction, forming elements and compounds that are found in the atmosphere (including nitrogen, oxygen, carbon dioxide, argon, and water). If these gases are under very high pressure as they move towards the surface of the earth, they are likely to form methane deposits, similar to thermogenic methane.

1.3 Natural Gas Under the Earth

Although there are several ways that methane, and thus natural gas, may be formed, it is usually found underneath the surface of the earth. As natural gas has a low density, once formed it will rise towards the surface of the earth through loose, shale type rock and other material. Most of this methane will simply rise to the surface and dissipate into the air. However, a great deal of this methane will rise up into geological formations that 'trap' the gas under the ground. These formations are made up of layers of porous, sedimentary rock (kind of like a sponge, that soaks up and contains the gas), with a denser, impermeable layer of rock on top. This impermeable rock traps the natural gas under the ground. If these formations are large enough, they can trap a great deal of natural gas underground, in what is known as a reservoir. There are a number of different types of these formations, but the most common is created when the impermeable sedimentary rock forms a 'dome' shape, like an umbrella that catches all of the natural gas that is floating to the surface.



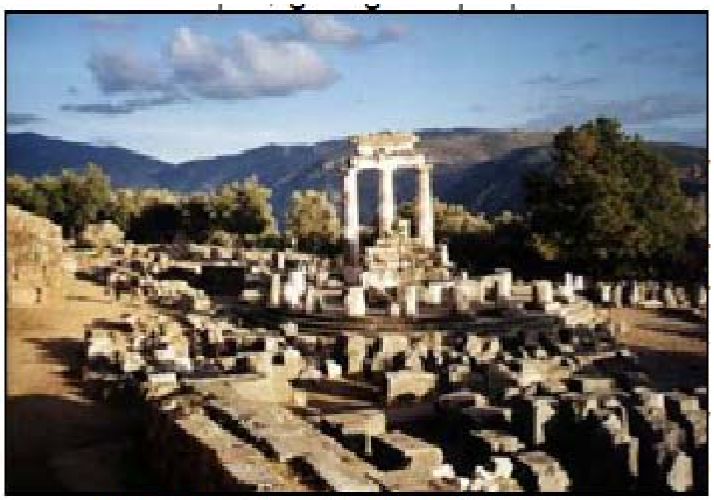
Source: U.S. Energy Information Administration

There are a number of ways that this sort of 'dome' may be formed. For instance, faults are a common location for oil and natural gas deposits to exist. A fault occurs when the normal sedimentary layers sort of 'split' vertically, so that impermeable rock shifts down to trap natural gas in the more permeable limestone or sandstone layers. Essentially, the geological formation which layers impermeable rock over more porous, oil and gas rich sediment has the potential to form a reservoir. The picture below shows how natural gas and oil can be trapped under impermeable sedimentary rock, in what is known as an anticlinal formation. To successfully bring these fossil fuels to the surface, a hole must be drilled through the impermeable rock to release the fossil fuels under pressure. Note that in reservoirs that contain oil and gas, the gas, being the least dense, is found closest to the surface, with the oil beneath it, typically followed by a certain amount of water.

With natural gas trapped under the earth in this fashion, it can be recovered by drilling a hole through the impermeable rock. Gas in these reservoirs is typically under pressure, allowing it to escape from the reservoir on its own.

Natural gas is nothing new. In fact, most of the natural gas that is brought out from under the ground is millions and millions of years old. However, it was not until recently that methods for obtaining this gas, bringing it to the surface, and putting it to use were developed.

Before there was an understanding of what natural gas was, it posed somewhat of a mystery to man. Sometimes, such things as lightning strikes would ignite natural gas that was escaping from under the earth's crust. This would create a fire coming from the earth, burning the natural gas as it seeped out from underground. These fires puzzled most early civilizations, and were the root of much myth and superstition. One of the most famous of these types of flames was found in ancient Greece, on Mount Parnassus approximately 1,000 B.C. A goat herdsman came across what looked like a 'burning spring', a flame rising from a fissure in the rock. The Greeks, believing it to be of divine origin, built a temple on the flame. This temple housed a priestess who was known as the Oracle of Delphi, giving out prophecies she claimed were inspired by the flame.



The Oracle at Delphi, Greece
Source: Pascal Troxler

These types of springs became prominent in the religions of India, Greece, and Persia. Unable to explain where these fires came from, they were often regarded as divine, or supernatural. It wasn't until about 500 B.C. that the Chinese discovered the potential to use these fires to their advantage. Finding places where gas was seeping to the surface, the Chinese formed crude pipelines out of bamboo shoots to transport the gas, where it was used to boil sea water, separating the salt and making it drinkable.

Britain was the first country to commercialize the use of natural gas. Around 1785, natural gas produced from coal was used to light houses, as well as streetlights.

Manufactured natural gas of this type (as opposed to naturally occurring gas) was first brought to the United States in 1816, when it was used to light the streets of Baltimore, Maryland. However, this manufactured gas was much less efficient, and less environmentally friendly, than modern natural gas that comes from underground.

Naturally occurring natural gas was discovered and identified in America as early as 1626, when French explorers discovered natives igniting gases that were seeping into and around Lake Erie. The American natural gas industry got its beginnings in this area. In 1859, Colonel Edwin Drake (a former railroad

A Natural Gas Streetlight
Source: DOE

conductor who adopted the title 'Colonel' to impress the townspeople) dug the first well. Drake hit oil and natural gas at 69 feet below the surface of the earth.

A Reconstruction of 'Colonel' Drake's First Well in Titusville, Pa
Source: API

Most in the industry characterize this well as the beginning of the natural gas industry in America. A two-inch diameter pipeline was built, running 5 and ½ miles from the well to the village of Titusville, Pennsylvania. The construction of this pipeline proved that natural gas could be brought safely and relatively easily from its underground source to be used for practical purposes.

In 1821, the first well specifically intended to obtain natural gas was dug in Fredonia, New York, by William Hart. After noticing gas bubbles rising to the surface of a creek, Hart dug a 27 foot well to try and obtain a larger flow of gas to the surface. Hart is regarded by many as the 'father of natural gas' in America. Expanding on Hart's work, the Fredonia Gas Light Company was eventually formed, becoming being the first American natural gas company.

During most of the 19th century, natural gas was used almost exclusively as a source of light. Without a pipeline infrastructure, it was difficult to transport the gas very far, or into homes to be used for heating or cooking. Most of the natural gas produced in this era was manufactured from coal, as opposed to transport from a well. Near the end of the 19th century, with the rise of electricity, natural gas lights were converted to electric lights. This led producers of natural gas to look for new uses for their product.

In 1885, Robert Bunsen invented what is now known as the Bunsen burner. He managed to create a device that mixed natural gas with air in the right proportions, creating a flame that could be safely used for cooking and heating.

A Typical Bunsen Burner
Source: DOE

The invention of the Bunsen burner opened up new opportunities for the use of natural gas in America, and throughout the world. The invention of temperatureregulating thermostatic devices allowed for better use of the heating potential of natural gas, allowing the temperature of the flame to be adjusted and monitored. Without any way to transport it effectively, natural gas discovered pre-WWII was usually just allowed to vent into the atmosphere, or burnt, when found alongside coal and oil, or simply left in the ground when found alone.

One of the first lengthy pipelines was constructed in 1891. This pipeline was 120 miles long, and carried natural gas from wells in central Indiana to the city of Chicago. However, this early pipeline was very rudimentary, and was not very efficient at transporting natural gas. It wasn't until the 1920's that any significant effort was put into building a pipeline infrastructure. However, it wasn't until after the World War II that welding techniques, pipe rolling, and metallurgical advances allowed for the construction of reliable pipelines. This post-war pipeline construction boom lasted well into the 60's, and allowed for the construction of thousands of miles of pipeline.

Once the transportation of natural gas was possible, new uses for natural gas were discovered. These included using natural gas to heat homes and operate appliances such as water heaters and oven ranges. Industry began to use natural gas in manufacturing and processing plants. Also, natural gas was used to heat boilers used to generate electricity. The transportation infrastructure had made natural gas easy to obtain, and it was becoming an increasingly popular form of energy.

1.4 How Much Natural Gas is there?

There is an abundance of natural gas in North America, but it is a non-renewable resource, the formation of which takes thousands and possibly millions of years. Therefore, understanding the availability of our supply of natural gas is important as we increase our use of this fossil fuel.

This section will provide a framework for understanding just how much natural gas there is in the ground available for our use, as well as links to the most recent statistics concerning the available supply of natural gas.

As natural gas is essentially irreplaceable (at least with current technology), it is important to have an idea of how much natural gas is left in the ground for us to use. However, this becomes complicated by the fact that no one really knows exactly how much natural gas exists until it is extracted. Measuring natural gas in the ground is no easy job, and it involves a great deal of inference and estimation. With new technologies, these estimates are becoming more and more reliable; however, they are still subject to revision. A common misconception about natural gas is that we are running out, and quickly. However, this couldn't be further from the truth. Many people believe that price spikes, such as were seen in the 1970's, and more recently in the winter of 2000, indicate that we are running out of natural gas. The two aforementioned periods of high prices were not caused by waning natural gas resources - rather, there were other forces at work in the marketplace. In fact, there is a vast amount of natural gas estimated to still be in the ground. In order to understand exactly what these estimates mean, and their importance, it is useful first to learn a bit of industry terminology for the different types of estimates.

1.4.1 Natural Gas Resource Estimates

Below are three estimates of natural gas reserves. The first, compiled by the Energy Information Administration (referred to as the EIA), estimates that there are 1,190.62 Tcf of technically recoverable natural gas in the United States.

Natural Gas Technically Recoverable Resources

Natural Gas Resource Category (Trillion Cubic Feet)	As of January 1, 2000
Nonassociated Gas	
Undiscovered	**247.71**
Onshore	121.61
Offshore	126.1
Deep	81.56
Shallow	44.52
Inferred Reserves	**232.7**
Onshore	183.03
Offshore	47.68
Deep	7.72
Shallow	39.96
Unconventional Gas Recovery	**369.59**
Tight Gas	253.83
Shale Gas	55.42
Coalbed Methane	60.35
Associated-Dissolved Gas	**140.89**
Total Lower 48 Unproved	**990.89**
Alaska	**32.32**
Total U.S. Unproved	**1023.21**
Proved Reserves	**167.41**
Total Natural Gas	**1190.62**

Source: Energy Information Administration - Annual Energy Outlook 2002

This includes undiscovered, unproved, and unconventional natural gas. As can be seen from the table, proved reserves make up a very small proportion of the total recoverable natural gas resources. The following table includes an estimate of natural gas resources compiled by the National Petroleum Council in 1999 in its report Natural Gas - Meeting the Challenges of the Nation's Growing Natural Gas Demand. Information on this report may be found here.

U.S. Natural Gas Resources
(Trillion Cubic Feet)

	1992 NPC Study	1999 NPC Study
	As of Jan 1, 1991	As of Jan 1, 1998
Lower 48 Resources		
Proved Reserves	160	157
Assessed Additional Resources	1135	1309
Old Fields (Reserve Appreciation)	236	305
New Fields	493	633
Nonconventional	406	371
Total Remaining Resources	**1295**	**1466**
Alaskan Resources		
Proved Reserves	9	10
Assessed Additonal Resources	171	303
Old Fields (Reserve Appreciation)	30	32
New Fields	84	214
Nonconventional	57	57
Total Remaining Resources	**180**	**313**
Total U.S. Remaining Resources	**1475**	**1779**

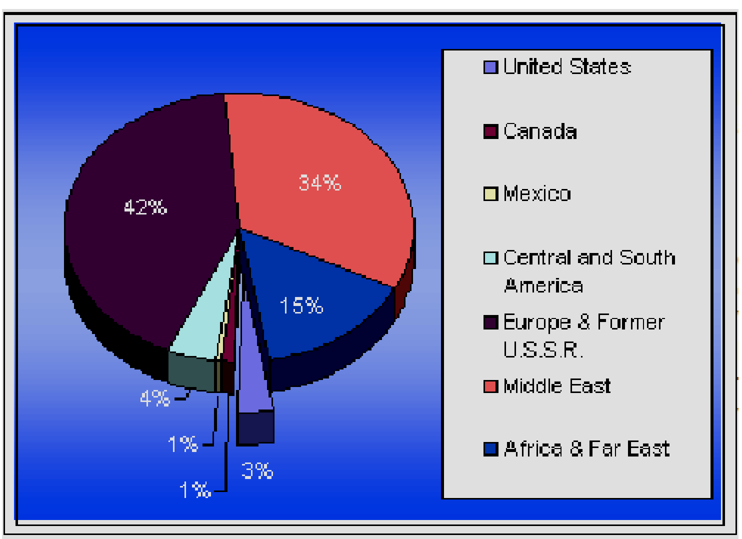
Source: National Petroleum Council - Meeting the Challenges of the Nation's Growing Natural Gas Demand, 1999

This estimate places U.S. natural gas resources higher than the EIA, at 1,779 Tcf remaining. It is important to note that different methodologies and systems of classification are used in various estimates that are completed. There is no single way that every industry player quantifies estimates of natural gas. Therefore, it is important to delve into the assumptions and methodology behind each study to gain a complete understanding of the estimate itself.
There are a myriad of different industry participants that formulate their own estimates regarding natural gas supplies, such as production companies, independent geologists, the government, and environmental groups, to name a few. While this leads to a wealth of information, it also leads to a number of difficulties. Each estimate is based on a different set of assumptions, completed with different tools, and even referred to with different language. It is thus difficult to get a definitive answer to the question of how much natural gas exists. In addition, since these are all essentially educated guesses as to the amount of natural gas in the earth, there are constant revisions being made. New technology, combined with increased knowledge of particular areas and reservoirs mean that these estimates are in a constant state of flux. Further complicating the scenario is the fact that there are no universally accepted definitions for the terms that are used differently by geologists, engineers, accountants, and others.

1.4.2 Where Are These Reserves?

Most of the natural gas that is found in North America is concentrated in relatively distinct geographical areas, or basins. Given this distribution of natural gas deposits, those states which are located on top of a major basin have the highest level of natural gas reserves. As can be seen from the map below, U.S. natural gas reserves are very concentrated around Texas and the Gulf of Mexico.

1.5 World Natural Gas Reserves

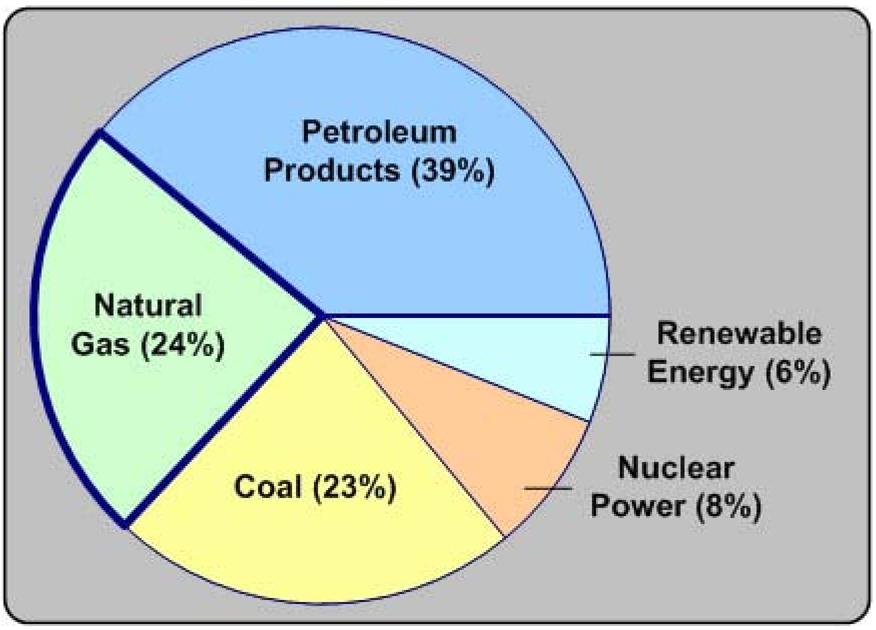


World Natural Gas Reserves - Jan 1, 2000
Source: International Energy Annual 1999 - EIA

The EIA, in conjunction with the Oil and Gas Journal and World Oil publications, estimates world proved natural gas reserves to be around 5,210.8 Tcf. As can be seen from the graph, most of these reserves are located in the Middle East with 1,836.2 Tcf, or 34 percent of the world total, and Europe and the Former U.S.S.R. with 2158.7, or 42 percent of total world reserves.

1.6 Uses Of Natural Gas

For hundreds of years, natural gas has been known as a very useful substance. The Chinese discovered a very long time ago that the energy in natural gas could be harnessed, and used to heat water. In the early days of the natural gas industry, the gas was mainly used to light streetlamps, and the occasional house. However, with much improved distribution channels and technological advancements, natural gas is being used in ways never thought possible.



There are so many different applications for this fossil fuel that it is hard to provide an exhaustive list of everything it is used for. And no doubt, new uses are being discovered all the time. Natural gas has many applications, commercially, in your home, in industry, and even in the transportation sector! While the uses described here are not exhaustive, they may help to show just how many things natural gas can do.

According to the Energy Information Administration, energy from natural gas accounts for 24 percent of total energy consumed in the United States, making it a vital component of the nation's energy supply.

Natural gas is used across all sectors, in varying amounts. The graph above gives an idea of the proportion of natural gas use per sector. The industrial sector accounts for the greatest proportion of natural gas use in the World, with the residential sector consuming the second greatest quantity of natural gas.

1.7 What is LNG?

Liquefied natural gas (LNG) is natural gas that has been cooled to the point that it condenses to a liquid, which occurs at a temperature of approximately -256 deg F (-161 deg C) and at atmospheric pressure. Liquefaction reduces the volume by approximately 600 times thus making it more economical to transport between continents in specially designed ocean vessels, whereas traditional pipeline transportation systems would be less economically attractive and could be technically or politically infeasible. Thus, LNG technology makes natural gas available throughout the world.

- Natural gas liquefaction dates back to the 19th century when British chemist and physicist Michael Faraday experimented with liquefying different types of gases, including natural gas.

- German engineer Karl Von Linde built the first practical compressor refrigeration machine in Munich in 1873.

- The first LNG plant was built in West Virginia in 1912. It began operation in 1917.

- The first commercial liquefaction plant was built in Cleveland, Ohio, in 1941. The LNG was stored in tanks at atmospheric pressure. The liquefaction of natural gas raised the possibility of gas transportation to distant destinations.

- To make LNG available for use, energy companies must invest in a number of different operations that are highly linked and dependent upon one another. The major stages of the ***LNG value chain****,* excluding pipeline operations between the stages, consist of the following:
- ***Exploration*** to find natural gas in the earth's crust and ***production*** of the gas for delivery to gas users. Most of the time natural gas is discovered during the search for oil.

- ***Liquefaction*** to convert natural gas into a liquid state so that it can be transported in ships.

- ***Shipping*** the LNG in special purpose vessels.

- ***Storage and Regasification*****,** to convert the LNG stored in specially made storage tanks, from the liquefied phase to the gaseous phase, ready to be moved to the final destination through the natural gas pipeline system.

1.8 Properties

- Extremely low temperature: minus 260°F (minus 162°C).
- LNG will float on water - Specific gravity of LNG is about 0.45. - Slightly less than half that of water.
- Odorless and colorless - LNG looks like boiling water. When exposed to atmospheric temperatures and pressure, it vaporizes to about 600 times its liquid volume.
- Nontoxic, non-corrosive.
- Vapor Dissipation - As the vapor warms to minus 160°F (minus 107°C); it becomes lighter than air and will dissipate. The natural gas vaporized from LNG can cause asphyxiation in an unventilated confinement.
- Explosion limit of LNG: 5 to 15%.
- Minimum ignition energy: 0.28mJ.
- Latent heat of vapourization: 510kJ/kg.

1.9 Some interesting facts about lng

- According to World Oil, for the year 2001, worldwide proven reserves of natural gas showed an increase of 8.4 percent over year 2000.
- According to LNGOne World 57, new LNG vessels were on order as of Dec 2002.
- The LNG tanker fleet size is estimated to continue to grow to 193 tankers by 2006.
- India to have 10 new LNG vessels by 2010.
- Orders received last year in marine shipbuilding industries, South Korea decreased relatively for almost all kinds of ships, except those for LNG carriers, which showed a 290% increase.

▪ The above data shows that world's is growing awareness in the field of natural gases. Now the question arises why there is so much increase in its demand. The solution can be obtained by comparative study of various resources of energy of which natural gas is also one.

- The prevailing energy resources are fast loosing its popularity in the modern world.
- Oil has been harshly criticized as pollutant
- Coal, having high sulphur content, is considered as bad as worst.
- Nuclear power has lately been considered as being long-term solution to the world's energy problems, but even nuclear power has