Natural gas

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1. Introduction

This chapter contains a description of background of natural gas: what exactly natural gas is?, how it is formed and how it is found in nature; history of natural gas: a brief history and development of modern natural gas; resources: how much abundance, where to find and what is the composition of natural gas; Uses: application and the important of energy source; natural gas versus environment: emission from the combustion of natural gas; natural gas technology: role of technology in the evolution of the natural gas industry; Purification of crude natural gas: various technologies used to convert sour to sweet natural gas; synthesis of artificial natural gas: methanation reaction.

2. Background of Natural Gas

A mixture of gaseous hydrocarbons occurring in reservoirs of porous rock (commonly sand or sandstone) capped by impervious strata. It is often associated with petroleum, with which it has a common origin in the decomposition of organic matter in sedimentary deposits. Natural gas consists largely of methane (CH_4) and ethane (C_2H_6), with also propane (C_3H_8) and butane (C_4H_{10})(separated for bottled gas), some higher alkanes (C_5H_{12} and above) (used for gasoline), nitrogen (N_2) , oxygen (O_2), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and sometimes valuable helium (He). It is used as an industrial and domestic fuel, and also to make carbon-black and chemical synthesis. Natural gas is transported by large pipelines or (as a liquid) in refrigerated tankers. Natural gas is combustible mixture of hydrocarbon gases, and when burned it gives off a great deal of energy. We require energy constantly, to heat our homes, cook our food, and generate our electricity . Unlike other fossil fuels, however, natural gas is clean burning and emits lower levels of potentially harmful byproducts into the air. 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 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

2.1 History of Natural Gas

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 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.

Fig. 1. A Reconstruction of 'Colonel' Drake's First Well in Titusville, Pa (Source: API)

Most in the industry characterize this well (Fig.1) 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 easy 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 the first American natural gas company.

In 1885, Robert Bunsen invented what is now known as the Bunsen burner (Fig.2). 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. 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 temperature-regulating thermostatic devices allowed for better use of the heating potential of natural gas, allowing the temperature of the flame to be adjusted and monitored.

Fig. 2. A Typical Bunsen Burner (Source:DOE)

Without any way to transport it effectively, natural gas discovered pre-world war II 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 did not transport natural gas efficiently. It wasn't until the 1920's that any significant effort was put into building a pipeline infrastructure. After World War II welding techniques, pipe rolling, and metallurgical advances allowed for the construction of reliable pipelines. This led to a post-war pipeline construction boom lasting well into the 60's, creating thousands of miles of pipeline in America.
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 made natural gas easier to obtain, and as a result expanded its uses.

2.2 How Natural Gas is Formed

Millions of years ago, the remains of plants and animals decayed and built up in thick layers. This decayed matter from plants and animals is called organic material –a compound that capable of decay or sometime refers as a compound consists mainly carbon. Over time,

the mud and soil changed to rock, covered the organic material and trapped it beneath the rock. Pressure and heat changed some of this organic material into coal, some into oil (petroleum), and some into natural gas – tiny bubbles of odorless gas. The main ingredient in natural gas is methane, a gas (or compound) composed of one carbon atom and four hydrogen atoms, CH_4. It is colorless, shapeless, and odorless in its pure form.
In some places, gas escapes from small gaps in the microscopic plants and animals living in the ocean rocks into the air; then, if there is enough activation energy from lightning or a fire, it burns. When people first saw the flames, they experimented with them and learned they could use them for heat and light. The formation of natural gas can be explained starting with microscopic plants and animals living in the ocean.
The process began in amillions of years ago, when microscopic plants and animals living in the ocean absorbed energy from the sun, which was stored as carbon molecules in their bodies. When they died, they sank to the bottom of the sea. Over millions of years, layer after layer of sediment and other plants and bacteria were formed.
As they became buried ever deeper, heat and pressure began to rise. The amount of pressure and the degree of heat, along with the type of biomass (biological materials derived from living organisms), determined if the material became oil or natural gas. More heat produced lighter oil. At higher heat or biomass made predominantly of plant material produced natural gas.
After oil and natural gas were formed, they tended to migrate through tiny pores in the surrounding rock. Some oil and natural gas migrated all the way to the surface and escaped. Other oil and natural gas deposits migrated until they were caught under impermeable layers of rock or clay where they were trapped. These trapped deposits are where we find oil and natural gas wells today where drilling process was conducted to obtain the gas.
In a modern technology, machines called "digesters" is used to turn today's organic material (plants, animal wastes, etc.) into synthetic natural gas (SNG). This replaces waiting for thousands of years for the gas to form naturally and could overcome the depletion of natural resources. The conventional route for SNG production is based on gasification of biomass to produce synthesis gas and then the subsequent methanation of the synthesis gas turn it to synthesis natural gas. Woody biomass contain 49.0% carbon and 5.7% hydrogen that can be converted to 76.8% methane, CH_4.

2.3 How Natural Gas is Obtained

Now imagine how to obtain the invisible treasure? That's the challenge face by geologist when exploring for natural gas. Sometimes there are clues on the earth's surface. An oil seeps is a possible sign of natural gas below, since oil and gas are sometimes found together. Geologists also have sensitive machines that can "sniff" surface soil and air for small amounts of natural gas that may have leaked from below ground.
The search for natural gas begins with geologists who locate the types of rock that are known to contain gas and oil deposits. Today their tools include seismic surveys that are used to find the right places to drill wells. Seismic surveys use echoes from a vibration source at the Earth's surface (usually a vibrating pad under a truck built for this purpose) to collect information about the rocks beneath. They send sound waves into the ground and measure how fast the waves bounce back. This tells them how hard and how thick the different rock layers are underground. The data is fed into a computer, which draws a

picture of the rock layers. This picture is called a seismogram. Sometimes, it is necessary to use small amounts of dynamite to provide the vibration that is needed.
The next task are taken by scientists and engineers who explore a chosen area by studying rock samples from the earth and taking measurements. If the site seems promising, drilling begins. Some of these areas are on land but many are offshore, deep in the ocean. Once the gas is found, it flows up through the well to the surface of the ground and into large pipelines. Some of the gases that are produced along with methane, such as butane and propane, are separated and the other sour gases such as carbon dioxide and hydrogen sulfide are cleaned at a gas processing plant (normally called as sweetening process). The by-products, once removed, are used in a number of ways. For example, propane and butane can be used for cooking gas.
Because natural gas is colorless, odorless and tasteless, mercaptan (a sulfur-containing organic compound with the general formula RSH where R is any radical, especially ethyl mercaptan, C_2H_5SH) is added before distribution, to give it a distinct unpleasant odor (like that of rotten eggs). This serves as a safety device by allowing it to be detected in the atmosphere, in cases where leaks occur.
Most of the natural gas consumed in the United States is produced in the United States. Some is imported from Canada and shipped to the United States in pipelines. Increasingly natural gas is also being shipped to the United States as liquefied natural gas (LNG).

2.4 How Natural Gas is Stored and Delivered

Natural gas is normally produced far away from the consumption regions, therefore they requires an extensive and elaborate transportation system to reach its point of use. The transportation system for natural gas consists of a complex network of pipeline, designed to quickly and efficiently transport natural gas from the origin to areas of high natural gas demand. Transportation of natural gas is closely linked with its storage since the demand of the gas is depend on the season.
Since natural gas demand is greater in the winter, gas is stored along the way in large underground storage systems, such as old oil and gas wells or caverns formed in old salt beds in western country. The gas remains there until it is added back into the pipeline when people begin to use more gas, such as in the winter to heat homes. In Malaysia, and other tropical country, gas is supplied throughout the year, therefore it was storage in a large tank in the processing plant, either in Bintulu, Sarawak, or at Kertih, Terengganu.
Three major types of pipeline available along the transportation route, the gathering system, the interstate pipeline and the distribution system. The gathering system consists of low pressure, low diameter pipelines that transport raw natural gas from the wellhead to the processing plant. In Malaysia, the natural gas is transported from oil rig offshore to the processing plant at Petronas Gas Berhad at Kertih, Terengganu, and Bintulu LNG Tanker, Sarawak. Since Malaysia natural gas and other producing country contain high sulfur and carbon dioxide (sour gaseous) it must used specialized sour gas gathering pipe. Natural wet gas from the wellhead contain high percentage of water therefore it will react with sour gaseous to form acids, which are extremely corrosive and dangerous, thus its transportation from the wellhead to the sweetening plant must be done carefully. The topic will be discussed in depth in the treatment and processing of natural gas.
Pipeline can be classified as interstate or intrastate either it carries natural gas across the state boundary (interstate) or within a particular state (intrastate). Natural gas pipelines are

subject to regulatory oversight, which in many ways determines the manner in which pipeline companies must operate. When the gas gets to the communities where it will be used (usually through large pipelines), the gas is measured as it flows into smaller pipelines called mains. Very small lines, called services, connect to the mains and go directly to homes or buildings where it will be used. This method is used by rich country such as in the United State, Canada or European country, such as United Kingdom, France etc.
The used of pipeline for natural gas delivery is costly, therefore some countries prefer to use trucks for inland delivery. Using this method the natural gas should be liquefied to minimize the size of the tanker truck. In certain country, the natural gas is transported by trucks tankers to the end users. For example in Malaysia the natural gas was transported as Liquefied Natural Gas (LNG) using tanker trucks to different state in peninsular of Malaysia and in East Malaysia. The gas was supplied by Petronas Gas Berhad, at Kertih, Terengganu while in east Malaysia, Sabah and Sarawak, the gas was supplied by Bintulu Plant. The natural is exported by large ships equipped with several domed tanks.
When chilled to very cold temperatures, approximately -260°F, natural gas changes into a liquid and can be stored in this form. Because it takes up only 1/600th of the space that it would in its gaseous state, Liquefied natural gas (LNG) can be loaded onto tankers (large ships with several domed tanks) and moved across the ocean to deliver gas to other countries. When this LNG is received in the United States, it can be shipped by truck to be held in large chilled tanks close to users or turned back into gas to add to pipelines. The whole process to obtain the natural gas to the end user can be simplified by the diagram shown in Fig. 3.

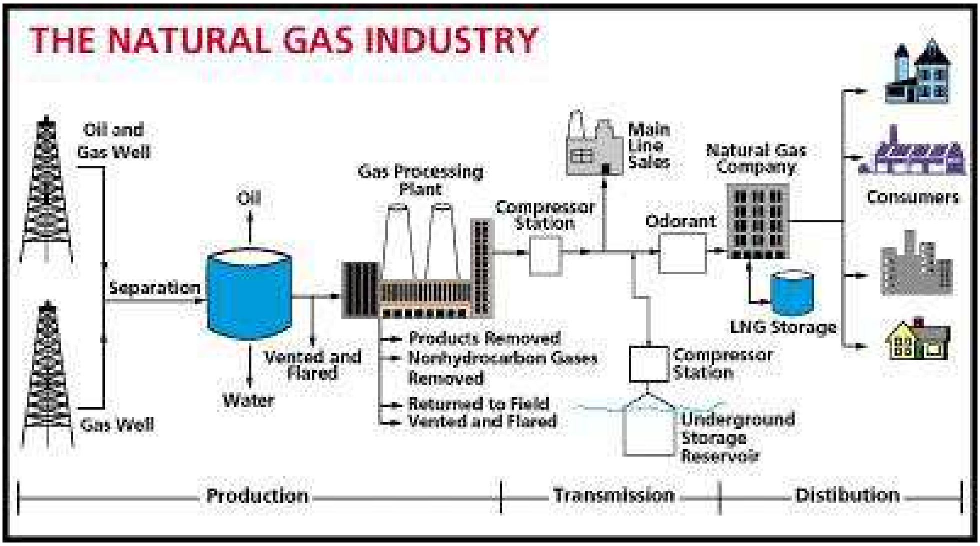

Fig. 3. Natural gas industry. Image (source: Energy Information Administration, DOE)

2.5 What is the Composition of 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.

Chemical Name	**Chemical Formula**	**Percentage (%)**
Methane	CH_4	70-90%
Ethane	C_2H_6	
Propane	C_3H_8	0-20%
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

Table 1. Typical composition of Natural Gas

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 CH_4. Malaysia producing sour natural gas. Before purification process, Malaysia's natural gas is consists of several gaseous and impurities. The chemical composition of Malaysia natural gas before it is being refined is shown in Table 2.

Chemical Name	**Chemical Formula**	**Percentage (%)**
Methane	CH_4	40-50%
Ethane	C_2H_6	5-10%
Propane	C_3H_8	1-5%
Carbon Dioxide	CO_2	20-3-%
Hydrogen sulphide	H_2S	0-1%

Table 2. Chemical composition in crude natural gas provided by Bergading Platform offshore of Terengganu, Malaysia.

2.6 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.

Natural Gas Resource Category	As of January 1, 2007(Trillion Cubic Feet)
Nonassociated Gas	
Undiscovered	**373.20**
Onshore	113.61
Offshore	259.59
Inferred Reserves	**220.14**
Onshore	171.05
Offshore	49.09
Unconventional Gas Recovery	**644.92**
Tight Gas	309.58
Shale Gas	267.26
Coalbed Methane	68.09
Associated-Dissolved Gas	**128.69**
Total Lower 48 Unproved	**1366.96**
Alaska	**169.43**
Total U.S. Unproved	**1536.38**
Proved Reserves	**211.09**
TOTAL NATURAL GAS	**1747.47**

Table 3. Natural Gas Technically Recoverable Resources (Source: Energy Information Administration - Annual Energy Outlook 2009)

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, 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.

The EIA provides classification system for natural gas resources. Unconventional natural gas reservoirs are also extremely important to the nation's supply of natural gas.

Below are three estimates of natural gas reserves in the United States. The first (Table 3), compiled by the Energy Information Administration (EIA), estimates that there are 1,747.47 Tcf of technically recoverable natural gas in the United States. This includes undiscovered, unproved, and unconventional natural gas. As seen from the table, proved reserves make up a very small proportion of the total recoverable natural gas resources in the U.S.

The following table includes an estimate of natural gas resources compiled by the National Petroleum Council (NPC) in 1999 in its report Natural Gas - Meeting the Challenges of the Nation's Growing Natural Gas Demand. 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.

	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**

Table 4. U.S. Natural Gas Resources (Trillion Cubic Feet) (Source: National Petroleum Council - Meeting the Challenges of the Nation's Growing Natural Gas Demand, 2007)

Below (Table 5) is a third estimate completed by the Potential Gas Committee. This estimate places total U.S. natural gas resources at just over 1,836 Tcf. This estimate classifies natural gas resources into three categories: probable resources, possible resources, and speculative resources, which are added together to reach a total potential resource estimate. Only this total is shown below.

	Total Potential Resource
Traditional Resources	
Lower 48 States	
Total Lower 48	**1479.6**
Alaska	
Onshore	94.432
Offshore	99.366
Total Alaska	**193.831**
Total Traditional	**1,673.4**
Coalbed Methane	**163.0**
Total United States	**1,836.4**

Table 5. Potential Natural Gas Resources of the U.S. (Trillion Cubic Feet) (Source: Potential Gas Committee - Potential Supply of Natural Gas in the United States, 2009)

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.

Natural gas has been discovered on all continents except Antarctica. World natural gas reserves total approximately 150 trillion cu m (5.3 quadrillion cu ft). The world's largest natural gas reserves, totaling, 50 trillion cu m (1.9 quadrillion cu ft) are located in Russia. The second-largest reserves, 48 trillion cu m (1.7 quadrillion cu ft), are found in the Middle East. Vast deposits are also located in other parts of Asia, in Africa, and in

Australia. Natural gas reserves in the United States total 5 trillion cu m (177 trillion cu ft). In Asia-Oceania, natural gas reserves total 12.6 trillion cu m (Table 6). Malaysia has the 14th largest gas reserves as at January 2008. As at January 2008, Malaysia's gas reserves stood at 88.0 trillion standard cubic feet (tscf) or 14.67 billion barrels of oil equivalent, approximately three times the size of crude oil reserves of 5.46 billion barrels.

	Proven reserves (Tm^3)	**Annual production (Gm^3)**	**Reserve to product (years)**
Australia	2.5	34.5	72.5
China	1.5	32.6	46.0
India	0.8	28.4	28.2
Indonesia	2.6	70.6	36.8
Malaysia	2.1	50.3	41.8
Others	3.1	85.3	36.3
Total	**12.6**	**301.7**	**41.8**

Table 6. Proven reserves and Annual production, Asia-Oceania. (Taken from BP Statistical Review, 2003)

Most of this gas reserves are located at offshore Peninsular Malaysia, Sarawak and Sabah. The Malaysian natural gas reserves are as shown in Figure 4 [4].

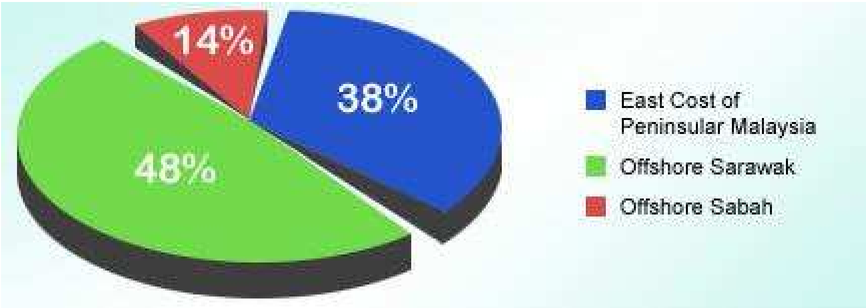

Fig. 4. Malaysian Natural Gas Reserve (Taken from Oil and Gas Exploration and Production-Reserves, Costs, Contract, 2004)

Currently, Malaysia is a net exporter of natural gas and is the third largest exporter after Algeria and Indonesia. In 2001, the country exported 49.7% of its natural gas production to the Republic of Korea and Taiwan under long-term contracts. The other 50.3% of Malaysia natural gas was delivered to the gas processing plants.

2.7 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, total energy (Fig. 5) from natural gas accounts for 23% of total energy consumed in the developing countries, making it a vital component of the nation's energy supply.

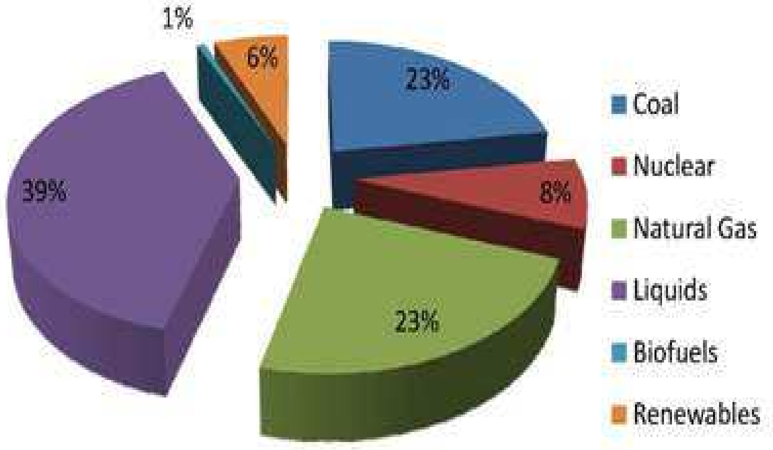

Fig. 5. Total Energy Consumed in the U.S. - 2007 (Source: EIA - Annual Energy Outlook 2009)

Natural gas is used across all sectors, in varying amounts. The pie chart below (Fig. 6) gives an idea of the proportion of natural gas use per sector. The residential sector accounts for the greatest proportion of natural gas use in the most of the developing countries, with the residential sector consuming the greatest quantity of natural gas.

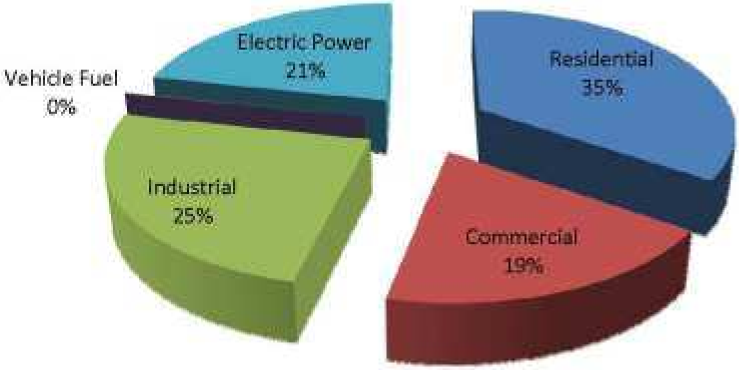

Fig. 6. Natural Gas Use By Sector (Source: EIA - Annual Energy Outlook 2009)

Commercial uses of natural gas are very similar to electric power uses. The commercial sector includes public and private enterprises, like office buildings, schools, churches, hotels, restaurants, and government buildings. The main uses of natural gas in this sector include space heating, water heating, and cooling. For restaurants and other establishments that require cooking facilities, natural gas is a popular choice to fulfill these needs.
According to the Energy Information Administration (EIA), as of the year 2003, the commercial sector consumes about 6,523 trillion Btu's of energy a year (aside from electrical system losses), most of which is required for space heating, lighting, and cooling. Of this 6,523 trillion Btu, about 2,100 trillion Btu (or 32.2%) are supplied by natural gas.

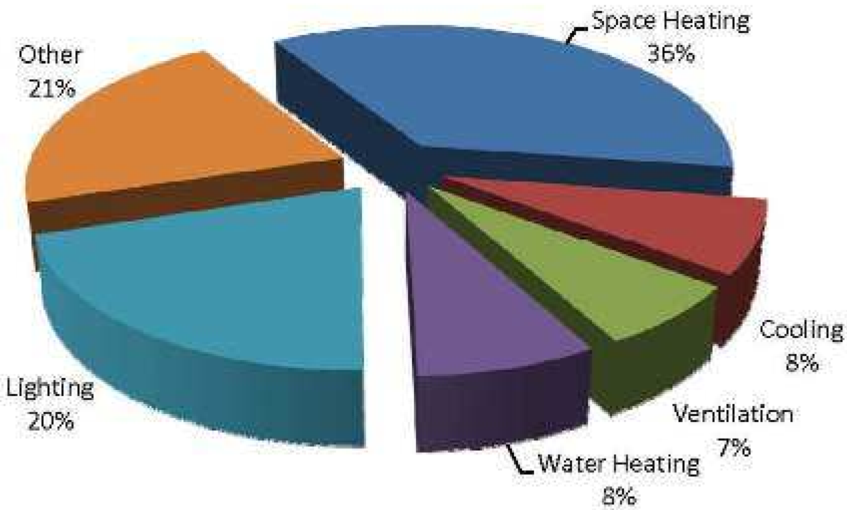

Fig. 7. Commercial Energy Use (Source: EIA Major Fuel Consumption by End Use, 2003.)

Natural gas space and water heating for commercial buildings is very similar to that found in residential houses. Natural gas is an extremely efficient, economical fuel for heating in all types of commercial buildings. Although space and water heating account for a great deal of natural gas use in commercial settings, non-space heating applications are expected to account for the majority of growth in natural gas use in the commercial sector. Cooling and cooking represent two major growth areas for the use of natural gas in commercial settings.
Natural gas currently accounts for 13 percent of energy used in commercial cooling, but this percentage is expected to increase due to technological innovations in commercial natural gas cooling techniques. There are three types of natural gas driven cooling processes. Engine driven chillers use a natural gas engine, instead of an electric motor, to drive a compressor. With these systems, waste heat from the gas engine can be used for heating applications, increasing energy efficiency. The second category of natural gas cooling devices consist of what are called absorption chillers, which provide cool air by evaporating a refrigerant like water or ammonia. These absorption chillers are best suited to cool large commercial buildings, like office towers and shopping malls. The third type of commercial cooling system consists of gas-based desiccant systems (Fig. 8). These systems cool by reducing humidity in the air. Cooling this dry air requires much less energy than it would to cool humid air.

Fig. 8. A Desiccant Unit Atop the Park Hyatt Hotel, Washington D.C. (Source: National Renewable Energy Laboratory, DOE)

Another area of growth in commercial natural gas use is in the food service industry. Natural gas is an excellent choice for commercial cooking requirements, as it is a flexible energy source in being able to supply the food service industry with appliances that can cook food in many different ways. Natural gas is also an economical, efficient choice for large commercial food preparation establishments. New developments such as Nontraditional Restaurant Systems, which provide compact, multifunctional natural gas

appliances for smaller sized food outlets such as those found in shopping malls and airports, are expanding the commercial use of natural gas. These types of systems can integrate a gas-fired fryer, griddle, oven, hot and cold storage areas, and multiple venting options in a relatively small space - providing the ease and efficiency of natural gas cooking while being compact enough to serve small kiosk type establishments.
In addition to traditional uses of natural gas for space heating, cooling, cooking and water heating, a number of technological advancements have allowed natural gas to be used to increase energy efficiency in commercial settings. Many buildings, because of their high electricity needs, have on-site generators that produce their own electricity. Natural gas powered reciprocating engines, turbines, and fuel cells are all used in commercial settings to generate electricity. These types of 'distributed generation' units offer commercial environments more independence from power disruption, high-quality consistent electricity, and control over their own energy supply.
Another technological innovation brought about is combined heating and power and combined cooling, heating and power systems, which are used in commercial settings to increase energy efficiency. These are integrated systems that are able to use energy that is normally lost as heat. For example, heat that is released from natural gas powered electricity generators can be harnessed to run space or water heaters, or commercial boilers. Using this normally wasted energy can dramatically improve energy efficiency.

Natural gas fired electric generation, and natural gas powered industrial applications, offer a variety of environmental benefits and environmentally friendly uses, including:

- Fewer Emissions - combustion of natural gas, used in the generation of electricity, industrial boilers, and other applications, emits lower levels of NO_x, CO_2, and particulate emissions, and virtually no SO_2 and mercury emissions. Fig. 9 shows a picture of emissions from Industrial Smokestacks (Source: EPA). Natural gas can be used in place of, or in addition to, other fossil fuels, including coal, oil, or petroleum coke, which emit significantly higher levels of these pollutants.
- Reduced Sludge - coal fired power plants and industrial boilers that use scrubbers to reduce SO_2 emissions levels generate thousands of tons of harmful sludge. Combustion of natural gas emits extremely low levels of SO_2, eliminating the need for scrubbers, and reducing the amounts of sludge associated with power plants and industrial processes.
- Reburning - This process involves injecting natural gas into coal or oil fired boilers. The addition of natural gas to the fuel mix can result in NO_x emission reductions of 50 to 70 percent, and SO_2 emission reductions of 20 to 25 percent.
- Cogeneration - the production and use of both heat and electricity can increase the energy efficiency of electric generation systems and industrial boilers, which translates to requiring the combustion of less fuel and the emission of fewer pollutants. Natural gas is the preferred choice for new cogeneration applications.
- Combined Cycle Generation - Combined cycle generation units generate electricity and capture normally wasted heat energy, using it to generate more electricity. Like cogeneration applications, this increases energy efficiency, uses less fuel, and thus produces fewer emissions. Natural gas fired combined cycle generation units can be up to 60 percent energy efficient, whereas coal and oil generation units are typically only 30 to 35 percent efficient.

- Fuel Cells - Natural gas fuel cell technologies are in development for the generation of electricity. Fuel cells are sophisticated devices that use hydrogen to generate electricity, much like a battery. No emissions are involved in the generation of electricity from fuel cells, and natural gas, being a hydrogen rich source of fuel, can be used. Although still under development, widespread use of fuel cells could in the future significantly reduce the emissions associated with the generation of electricity.
- Essentially, electric generation and industrial applications that require energy, particularly for heating, use the combustion of fossil fuels for that energy. Because of its clean burning nature, the use of natural gas wherever possible, either in conjunction with other fossil fuels, or instead of them, can help to reduce the emission of harmful pollutants.

Fig. 9. Emissions from Industrial Smokestacks (Source: EPA)

3. Purification of Natural Gas

Gas processing of acidic crude natural gas is necessary to ensure that the natural gas intended for use is clean-burning and environmentally acceptable. Natural gas used by consumers is composed almost entirely of methane but natural gas that emerges from the reservoir at the wellhead contains many components that need to be extracted. Although, the processing of natural gas is less complicated rather than the processing and refining of crude oil, it is equal and necessary before it can be used by end user.

One of the most important parts of gas processing is the removal of carbon dioxide and hydrogen sulfide. The removal of acid gases (CO_2, H_2S and other sulfur components) from natural gas is often referred to as gas sweetening process. There are many acid gas treating processes available for removal of CO_2 and H_2S from natural gas. These processes include Chemical solvents, Physical solvents, Adsorption Processes Hybrid solvents and Physical separation (Membrane) (Kohl and Nielsen, 1997).

3.1 Various Technologies Used to Convert Sour to Sweet Natural Gas

According to previous research done by Hao *et al.* (2002), there are ways to upgrading the low quality natural gas with selective polymer membranes. The membrane processes were designed to reduce the concentrations of CO_2 and H_2S in the natural gas pipeline specifications. However, this technique incurs high cost and low selectivity towards toxic gas separation. This technique also needs further development because the performance of membrane depends upon the specific characteristics of flue gas composition, and the specific features of the separation (i.e. large volumetric flow rate, low pressure source, high temperature, and the relative low commodity value of H_2S and CO_2) (Rangwala, 1996).

Another method of H_2S removal and one that leaves the CO_2 in the natural gas is called the Iron Sponge process. The disadvantage of this is that it is called a batch-type function and is not easily adapted to continuous operating cycle. The Iron Sponge is simply the process of passing the sour gas through a bed of wood chips that have been impregnated with a special hydrated form of iron oxide that has a high affinity for H_2S. Regeneration of the bed incurs excessive maintenance and operating costs, making this method inconsistent with an efficient operating program. If there are any real advantages in using this process, it is fact that CO_2 remains in the gas, thereby reducing the shrinkage factor which could be significant for very large volumes with an otherwise high CO_2 content (Curry, 1981).

Chemical absorption processes with aqueous alkanolamine solutions are used for treating gas streams containing CO_2. They offer good reactivity at low cost and good flexibility in design and operation. However, depending on the composition and operating conditions of the feed gas, different amines can be selected to meet the product gas specification (Mokhatab et al., 2006). Some of the commonly used alkanolamine for absorption desulfurization are monoethanolamine (MEA), diethanolamine (DEA), triethanolamine (TEA), diglycolamine (DGA), di-isopropanolamine (DIPA) and methyldiethanolamine (MDEA). MDEA allows the selective absorption of H_2S in the presence of CO_2 but can be use effectively to remove CO_2 from natural gas in the present of additives (Salako and Gudmundsson, 2005).

In the other hand, CO_2 can be removed from natural gas via chemical conversion techniques. Catalysts for CO_2 methanation have been extensively studied because of their application in the conversion of CO_2 gas to produce methane, which is the major component in natural gas (Wan Abu Bakar *et al.*, 2008a). Usually, the catalysts are prepared from the metal oxide because of the expensiveness of pure metal. This process can increase the purity and quality of the natural gas without wasting the undesired components but fully used them to produce high concentration of methane (Ching Kuan Yong, 2008).

3.2 Synthesis of Artificial Natural Gas: Methanation Reaction

Methane (CH_4) gas was formed from the reaction of hydrogen gas and carbon dioxide gas through methanation process by reduction reaction as in Equation 1.1 below:-

$$CO_{2\,(g)} + 4H_{2\,(g)} \rightarrow CH_{4\,(g)} + 2H_2O_{\,(l)} \quad (1.1)$$

This reaction is moderately exothermic, H^o = -165 kJ/mol. In order for this method to be effective, a suitable catalyst must be applied to promote selectively CO_2 methanation because of the main side product under this reaction also will be form (Eq 1.2), which obviously should be avoided. Thus, high selectivity of the catalyst in promoting CO_2