The Role of Natural Gas as a Primary Fuel in the Near Future, Including Comparisons of Acquisition, Transmission and Waste Handling Costs of Gas with Competitive Alternatives

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Introduction

Natural gas as an energy source comprises about a quarter of the United States' energy use. Natural gas is more environmentally friendly than oil and coal due to lower carbon emissions per unit, less costly per unit of energy, more readily available domestically, and in abundant supply. However, due to a number of barriers in both the political, infrastructural, pricing and other arenas, the use of natural gas as a significant energy source in the United States has thus been limited. In our paper, we highlight the favorable qualities of natural gas and its benefits for the consumer, producer, and environment, having compared the costs of the various components of the natural gas business such as drilling and transport to that of coal and oil. Moreover, we touch upon the major issues that have prevented a more prevalent use of the gas, such as the fact that the infrastructure of natural gas is more costly since it is transported though pipelines whereas other energy sources such as oil and coal have flexible systems that use rains, trucks and ships. In addition, the powerful lobbies of the coal and oil businesses along with recently passed bills that create further incentives for these industries pose an even greater barrier for natural gas, despite its various attractive qualities. We also include discussions of policy proposals to incentive greater use of natural gas in the future.

Natural gas is formed in the earth's crust as a result of transformation of organic matter due to heat and pressure of overlying rock. The gas hydrocarbons can also be produced as a result of microbial decomposition of organic substances and also due to reduction of mineral salts. Some of these gases are released into the atmosphere or hydrosphere while the rest accumulates in the upper layers of the earth's crust.

The composition of natural gas varies depending on a number of factors like the origin, location of deposit and geological structure. Natural gas mainly consists of saturated aliphatic hydrocarbons like methane. Components such as carbon dioxide, hydrogen sulfide, nitrogen and helium constitute an insignificant proportion of natural gas composition. Natural gas is the cleanest of all fossil fuels and the main products of combustion of natural gas are carbon dioxide and water vapor. Coal and oil are composed of much more complex molecules and when combusted, they release higher levels of harmful emissions such as nitrogen oxides and sulfur dioxide. They also release ash particles into the environment.

The combustion of natural gas releases very small amounts of nitrogen oxides and sulfur dioxide, carbon dioxide, carbon monoxide and other reactive hydrocarbons and virtually no particulate matter.

Fossil Fuel Emission Levels

- Pounds per Billion Btu of Energy Input

Pollutant	**Natural Gas**	**Oil**	**Coal**
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Natural gas can be used in many ways to help reduce the emissions of pollutants into the atmosphere as it emits fewer harmful pollutants and an increased reliance on natural gas can potentially reduce the emission of many of these harmful pollutants. In the United States the pollutants emitted from the combustion of fossil fuels have led to the development of a number of pressing environmental problems that include:

- Greenhouse gas emissions
- Smog, air quality and acid rain
- Pollution from the transportation sector
- Electrical and industrial generation emissions

Greenhouse effect is an environmental issue that deals with the potential for global climate changes due the increased levels of atmospheric greenhouse gases. Scientists claim that an increase in greenhouse gases will lead to increased temperature around the globe. The principle greenhouse gases include carbon dioxide and water vapor, methane and nitrogen oxides. The levels of greenhouse gases in the atmosphere have been increasing due to the widespread burning of fossil fuels by the growing human populations.

The main component of natural gas, methane is itself a potent greenhouse gas. Methane emissions account for only 1.1% of the total U.S. greenhouse gas emissions, they account for 8.5% of the greenhouse gas emissions based on global warming potential. A study performed by the EPA (Environment Protection Agency) and the GRI (Gas Research Institute) in 1997 lead to the conclusion that the reduction of emissions from increased natural gas use would strongly outweighs the detrimental effects of increased methane emissions. Therefore the increased use of natural gas can serve to reduce the emission of greenhouse gases in the United States.

Smog is formed by a chemical reaction of carbon monoxide, nitrogen oxides, volatile organic compounds and heat from sunlight. Ground level ozone and smog can contribute to respiratory problems that range from temporary discomfort to permanent lung damage.

The use of natural gas does not contribute to the formation of smog as it emits low levels of nitrogen oxides and no particulate matter. Increased natural gas use could be served to combat smog production. This would reduce the emissions of smog causing chemicals and result in healthier air.

Acid rain is formed when sulfur dioxide and nitrogen oxides react with water vapor and other chemical in the presence of sunlight. The increased use of natural gas could provide for fewer acid rain causing emissions.

Natural gas powered industrial application and natural gas fired electric generation offer a variety of environmental benefits and environmentally friendly uses that include:

- Fewer emissions
- Reburning
- Reduced sludge
- Cogenerations
- Fuel cells
- Combined cycle generation.

Use of natural gas

Natural gas has a number of applications commercially in homes, industries and the transportation sector.

Residential use

Natural gas is one of the cheapest forms of energy available to residential consumers; it is even cheaper than electricity as a source of energy.

According to Department of Energy, in 2007 natural gas was the lowest cost conventional energy source available for energy use; it costs less than 30% the cost of electricity, per British thermal unit (Btu).

Energy source	Residential energy costs per Btu
Kerosene	19.48
Propane	20.47
No. 2 Heating Oil	16.01
Natural Gas	12.18
Electricity	31.21

Natural gas is used for heating and cooking. Cooking with natural gas provides benefits like easy temperature control, self-ignition and self-cleaning. A gas range costs about half that of an electric range and it has quick heat ability. The newer generation natural gas ranges are most efficient, economical and versatile cooking appliances.

Natural gas is the most popular fuel for residential heating. According to American gas association (AGA), 51% of the heated homes in US used natural gas heating in 2000.

Natural gas air conditioning units, like many other gas powered appliances are initially more expensive than electric ones but they are cheaper to operate and they have longer expected life and require low maintenance. All gas-powered appliances offer a safe, efficient, and economical alternative to other fuel sources.

Almost 70% of the new homes in USA use natural gas for heating and therefore a large number of them already have natural gas delivery infrastructure in place. Gas pipes that can supply gas to furnaces can be used to supply energy for all gas-powered appliances, thus installation is easy.

Natural gas cannot be substituted for electricity in case of appliances like blenders, televisions and blenders.

Natural gas fuel cells and micro turbines offer residential consumers the capacity to disconnect from their local electric distributor, and generate just enough electricity to meet their requirements. This technology is still in its starting stages but is promising in being able to provide independent, efficient, reliable and environmentally friendly electricity for residential needs

Commercial Uses

The main commercial uses of natural gas include space heating, water heating and cooling.

Commercial Energy Use	Percentage
Space Heating	36%

Cooling	8%
Ventilation	7%
Water heating	8%
Lighting	20%
Other	21%

According to the Energy Information Administration, as of the year 2003, the commercial sector consumed about 6,523trillion Btu's of energy annually (minus electrical system losses) most of which is required for heating, lighting and cooling.

Natural gas is an efficient and economical fuel for commercial buildings. Non-space heating applications of natural gas are expected to account for the majority of the growth of natural gas use in the commercial sector.

Natural gas provides 13% of the energy used in commercial cooling but this percentage is expected to increase due to technological innovations in commercial natural gas cooling techniques.

There has been a growth in the demand for natural gas in the food service industry. Natural gas is a flexible energy source and natural gas–powered appliances can cook food in many different ways that are economical, efficient for large commercial food preparation establishments.

Smaller systems that use natural gas can integrate gas-fired fryer, griddle, over, hot/cold storage areas and multiple venting options in a small space as natural gas-powered appliances can be easy and efficient while being compact.

Technological advancements allow natural gas to be used to increase energy efficiency in commercial settings. Natural gas-powered fuel cells, reciprocating engines and turbines can generate electricity. These units offer commercial environments more independence from power disruption, consistent high-quality electricity and control over their own energy supply.

Combined heating and power (CHP) and combined cooling, heating and power (CCHP) systems are used to increase energy efficiency. These systems are able to use energy that is normally lost in the form of heat and using this energy that is normally wasted, energy efficiency can be dramatically improved.

Use in Industry

Industrial uses include:

Natural gas helps provide base ingredients for products like plastic, fertilizer, anti-freeze and fabrics. Industry accounts for about 25% of natural gas use across all sectors. Natural gas is the second most used energy source in industry after electricity.

Natural gas is used primarily in the metal, chemical, petroleum refining, stone, clay and glass, pulp and paper, plastic and food-processing industries. These businesses account for more than 84% of the total industrial natural gas use.

Natural gas is used for waste treatment and incineration, metal preheating, glass melting, drying and dehumidification, food processing and fueling industrial boilers.

Natural gas is used as feedstock for the manufacturing of a number of chemicals and products and as a building block for methanol, which has a number of industrial applications. Natural gas is converted to synthesis gas (a mixture of hydrogen and carbon oxides formed by the process of steam reforming. In the process, natural gas is exposed to a catalyst that causes oxidization of natural gas when brought in contact with steam).

Synthesis gas is used to make methanol (can be used as fuel source in fuel cell) – used to make substances like formaldehyde, MTBE (methyl tertiary butyl ether, (it is an additive for cleaner burning gasoline) and acetic acid.

Gases like butane, propane and ethane can be extracted from natural gas and these may be used as feedstock for products like fertilizers and pharmaceutical products.

Natural gas desiccant systems (used for dehumidification) are used in pharmaceutical, plastic, candy and recycling industries. The absorption systems used to heat and cool water in and economical, efficient and environmentally sound way.

INFRARED Heating Units

Natural gas is used for infrared (IR) heating units and it is an innovative and economic method of used natural gas to generate heat. IR heating units increase efficiency of powder-coating manufacturing processes. IR heaters heat materials more efficiently and quickly. Natural gas +

panel of ceramic fibers containing a platinum catalyst = reaction with oxygen that dramatically increases temperature without producing flame. Using natural gas in this manner increases the speed of manufacturing process + it is an economic alternative to electricity.

Direct contact water heaters

Energy from combustion of natural gas is directly transferred from the flame into the water. It is an efficient application for water heating. While normal industrial water heaters operate at 60-70% energy efficiency range, direct contact water heaters can achieve an efficiency of up to 99.7%. Therefore, there are cost savings in industries where water heating is required.

Industrial combined heat and power

Industrial consumers get great benefits from operating natural gas combined cooling, heat and power (CCHP) systems and Combined Heat and Power(CHP) systems. Natural gas may be used to generate electricity in a certain industrial setting, the excess heat and steam produced by this process may be used to fulfill other industrial applications such as space heating, water heating and to power industrial boilers. Increased efficiency saves money. Burning attributes of natural gas helps industries reduce harmful emissions.

Industrial co-firing

Natural gas co-firing technologies help increase industrial energy efficiency and reduce harmful atmospheric emissions. Co-firing – process where natural gas is used as a supplemental fuel in combustion of other fuels like coal, biomass energy and wood. Using natural gas can improve the operational performance of the boiler including its energy efficiency. Co-firing can be used to generate electricity.

Natural gas is a clean, efficient source of energy and a chemical building block, which is an important part of successful, and environmentally sounds industry in the USA.

Natural gas in the transportation sector

According to natural gas vehicle coalition estimates there are 120,000 natural gas vehicles (NGVs) in USA and more than 8.7million NGVs worldwide. There are about 1,100 natural gas fueling stations in USA alone.

Disadvantages of NGV like limited range, trunk space, higher initial cost, lack of refueling infrastructure are impediments to future spread of NGV. Some natural gas vehicles are bi-fuel, so there is flexibility of fuel choice. Many of these vehicles were originally just gasoline but have been converted to be bi-fuel. Conversion is costly and results in less efficient use of natural gas.

Newer, strict federal and state emission laws require an improvement in vehicle emissions, and natural gas is the cleanest burning alternative transportation fuel available and it offers the opportunity to meet the strict environmental emission standards.

Natural gas is safe and lighter than air so when there is an accident, natural gas just dissipates into the air and does not form a dangerous flammable pool on the ground like other fuels. There is no pollution of ground water in event of spill. The natural gas storage tanks on NGVs happen to be stronger and sturdier than gasoline tanks.

Natural gas is an economic alternative to other transportation fuels. NGVs are about 30% cheaper than gasoline vehicles to refuel and maintenance costs lower. Natural gas abundance domestically can help decrease US dependence on foreign oil…therefore, more secure, safe energy supply for USA.

Natural gas use reduces environmentally harmful emissions. The vehicles on the road account for 60% of the carbon monoxide pollution, 31% of the nitrogen oxides and 29% of the hydrocarbon emissions in USA. These emissions contribute to smog pollution and increase dangerous ground level ozone. Vehicles account or over half of all dangerous air pollutants and about 30% f the total carbon emissions in the USA. This contributes to the presence of greenhouse gases in the atmosphere. The environmental effects of NGV are less detrimental than that of others.

Due to the chemical composition of natural gas, NGVs are much cleaner burning than others. Natural gas – methane mainly – emits small amounts of ethane, propane and butane. Gasoline/diesel fuels – contains harmful compounds – emits sulfur dioxide and nitrogen oxides (combine in atmosphere to produce ground level ozone), arsenic, benzene, nickel and over 40 other toxic substances.

NGV produces on average 70% less carbon monoxide, 80% less nitrogen oxides and 87% less non-methane organic gas than other vehicles.

Electricity Generation Using Natural Gas

In 2009, 23,475MW of new generation capacity are planned in the USA, out of which, 50% (12,334MW) will be natural gas fired additions. Coal is the cheapest fossil fuel for generating electricity, but at the same time it is the dirtiest. It releases the highest levels of pollutants into the air. The electricity generation industry happens to be one of the most polluting industries in the USA. New technology allows, cleaner generation of electricity using natural gas.

Natural gas is used in steam generation units, centralized gas turbines, combined cycle units, locomotives, distributed generation, industrial natural gas fired turbines, micro turbines and fuel cells.

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Background

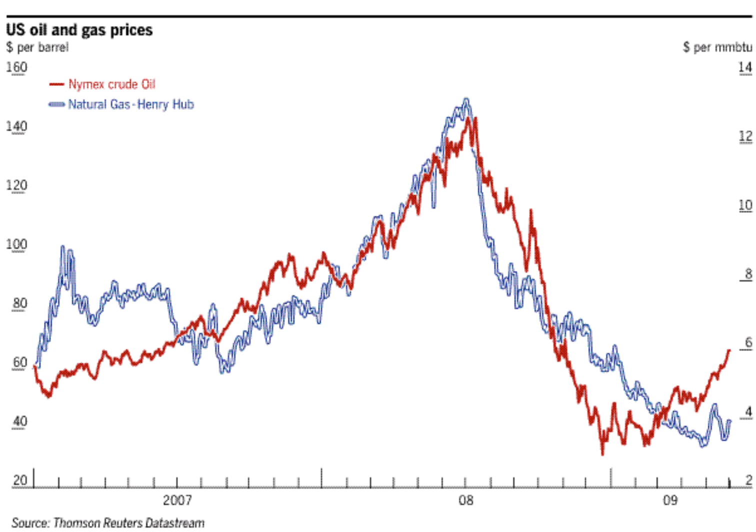
Before the 1980s the price of gas generally rose and fell with oil prices. There are many reasons to this, one of the prominent reasons being that gas contracts used to be negotiated with links to crude oil or oil products, especially in IEA[1] regions. Since then however, both oil and gas markets has been driving towards liberalization/ unbundling of network assets[2]. An instance of this is the introduction of futures contract for natural gas in the 1990 by the New York Mercantile Exchange, and the creation of "hub pricing", which is an efficient way to coordinate multiple players in the gas industry by delivering up to date information on the price of natural gas. This is especially important to pipeline companies that set up trading facilities in order to market their capacity services and gain higher utilization factors for their pipelines, infrastructure builders who uses the prices at two points in the system as an indicator for the need for new pipeline infrastructure. The volatility of these hub prices also signals to gas customers as a good indicator for more investment in storage. The hub system is becoming increasingly prevalent in North America and gas is now traded at over 40 principal centers across the North American continent, the best known being the Henry Hub in Louisiana, which

[1] International Energy Agency (IEA) is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy

[2] Part of the liberalization program is the unbundling of natural gas services. The Dutch company Gasunie was the first Continental gas companies to offer services a la carte and many other companies followed. In the US, The FERC Order No. 436 make it a necessary for pipelines to separate their transportation and sales services so that the customers have a choice in selecting provider and quantity of their gas sales, transportation and storage services. This is supposed to reduce the monopoly of pipeline companies and punish many economic 'rent seekers' in order to facilitate more efficient and reliable delivery of natural gas to ends users.
With the unbundling of services, customers are free to decide for themselves how much flexibility and back-up they require. Instead of contracting for a guaranteed supply under all circumstances (such as temperature variation) each customer can The only responsibility left for the commercial players are the contractual obligations they must fulfill.
See Appendix (Deregulation) for more information

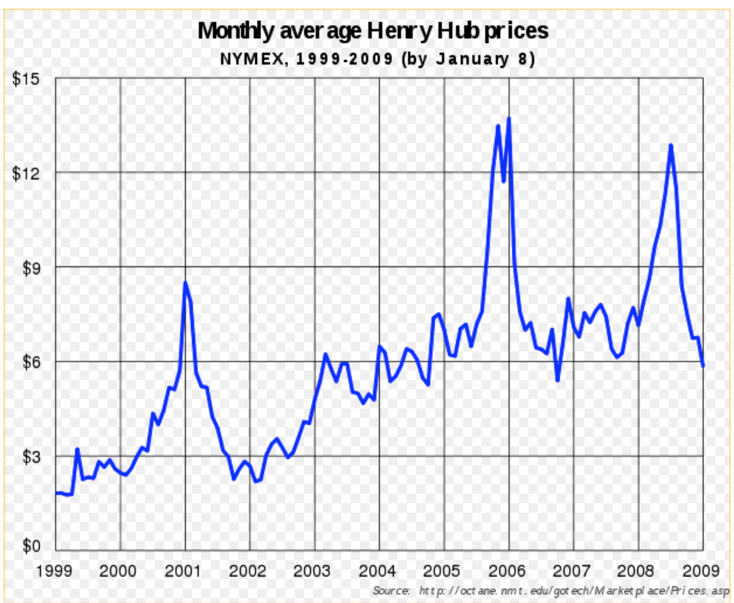
is the reference point of gas for the NYMEX gas future contract. Such innovative financial instruments allows for the development of a spot market for natural gas, which ensured that gas price reflect underlying issues of demand and supply (e.g. the availability of power plants, hydro levels, gas storage levels, oil prices, pipelines, temperature, level of industrial or commercial demand…etc) and not just “track” that of oil prices. Nonetheless, this is not to say that gas pricing cannot track oil prices, for to the extent that they are substitutable, the price of one will definitely have the effect on the price of another.

It should be noted however, that while gas prices have been decontrolled at the wellhead and at the bulk or wholesale level, the prices of transportation and storage services (which makes up a large part of the end user prices) remain on the large part regulated but the governmental authorities



An interesting aspect about the above graph is that at some points it seems like gas and oil prices are inversely related (before 2007 for example, a dip in crude oil prices is accompanied by a rise peaking in natural gas prices, the reverse is true once we hit 2007, and we witness familiar dips and peaks at times through 2008-2009). This inverse relationship in price is indicative of the high competitiveness of natural gas relative to oil (that the rise in price of one would lead to the dip in the price of another due to fuel switching).

<u>Gas Price trends in North America</u>



Ideally, liberalization is supposed to lower prices/costs and allow consumers better access to resources. However, in the case of North America, prices have been gradually increasing since the 1990s. Not only so, there has also been increased volatility in natural gas prices (the historical price volatility of natural gas has always been 20% higher than that of crude oil). To understand this combined phenomena, one should first understand the underlying powers of supply and demand of natural gas.

There are some features inherent in the natural gas market that influences the structure of its price:

1) Prices of natural gas generally track the wellhead price (price of the natural gas itself as a commodity), long distance transportation cost and local distribution cost

2) The large economies of scale associated with pipeline transmission system tend toward a natural monopoly. In this sense, a spot market for natural gas prices may not be favorable as it can stifle long term contracting, hence investments.

3) There is no exclusive end-user market in which natural gas dominates. Instead, it competes in every main use with other fuels , be it power generation, domestic heating, industrial, petrochemicals…etc
4) The natural gas market in each region is influenced by the structure of entire energy market complex in each region, and by existing gas infrastructure and potential prospects for its future expansion
5) Natural gas usually has large fixed to variable costs (fixed cost being start up capital, infrastructure…etc variable being transmission and associated costs). This usually necessitates longer term contracts in order to shift some of the large fixed costs onto consumers.
6) Indeed, balance needs to be found to smoothen the tension between the high fixed cost and low average marginal costs in order to ensure short term competitiveness without jeopardizing long term investment incentives
7) It generally has low income elasticity
8) Different end users of natural gas have different elasticities of demand, the residential/commercial consumers are generally the least responsive to a change in price due to their inability to access viable substitutes

Point 2) is especially important because unlike oil, gas is an infrastructure driven industry. This means that its price depends on a series of regional markets in which separate development depend on the nature of infrastructure and regulations in place. For this reason, gas suppliers are more exposed to the risk of disruption than oil producers. In the case of oil, temporary supply shortages can be dealt with by "transporting" oil (by tanker, truck, plane or railroad) to the emergency region. On the other hand, gas requires fixed installations that are highly costly and cannot be constructed in a hurry. As a result, all gas users that are not located in the immediate vicinity of a gas field, a pipeline hub or a LNG terminal will face a dangerous risk of not being to access gas. This is a competitive drawback that cannot be ignored.

The extent to which such temporary supply shocks are "dangerous" should not be exaggerated, for different users have different supply needs. For example, large industrial users usually have the ability to substitute heating oil or coal, so they do not need a contract that protects them entirely from supply shocks. On the contrary, they might even prefer contracts that do not protect them from the supply shocks because they will not need to pay the "risk premium". On the other hand, power generators with shifting requirements need greater security in supply, but the most venerable group is still the residential/public service/commercial consumers without substitution ability. Indeed, commercial consumers generally pay higher prices to enjoy protection through statutory distributor storage requirements and priority services.

One can argue that the supply risk associated with natural gas does not actually prevent it from achieving an efficient outcome. The people who need more supply security will just end up pay more. In the long run however, as oil becomes increasingly scarce and we look to natural gas as a viable option, we should aim to make natural gas more competitive in the commercial sector by reducing the supply risks, and thus the premiums paid by the consumers.

US Demand of Natural Gas

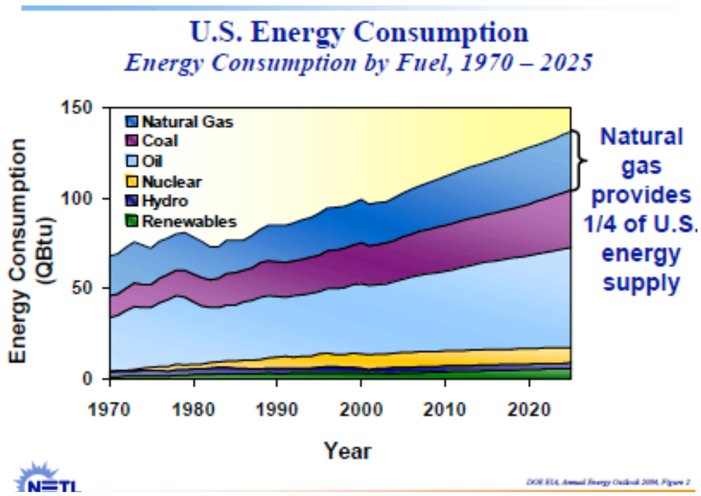
The North American gas market[3] is the largest in the world with 773 bcm consumed in 2001, or 29% of global gas demand. The US accounts for 608 bcm.

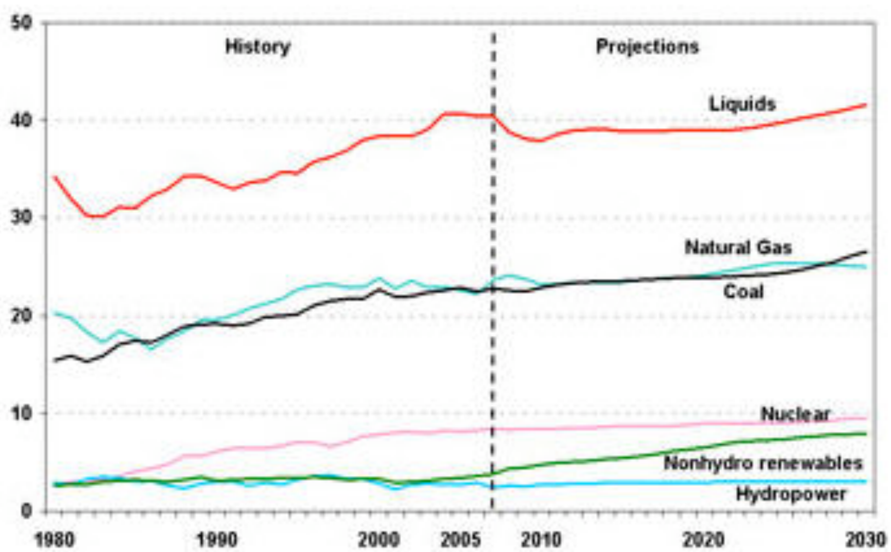
US gas demand has been steadily rising from 1980s. Domestically, natural gas currently accounts for almost a quarter of all energy in the US. It heats 50% of existing home and nearly 70% of newly built homes. Gas fired power plants makes up 88% of total new electrical power plants.

In the past couple of years, the gas-fired share of US electricity generation, including co-generation, rose to close to 20%. Electricity generation is expected to surpass the industrial sector as the largest consumer I natural gas in the US.

The EIA estimates that natural gas demand in the US could be 24. 36 Tcf by the year 2030, which is equal to a 6% increase from 2007 demand levels, as compared to an expected total energy consumption increase (from all energy sources) of 12 %. Furthermore, it is predicted that the annual will demand increase at a rate of 0.5 percent over the next 21 years

[3] We may speak of Canada and the US as a single network as both countries have similar regulatory frameworks and both are NAFTA members. Large pipeline links also carry substantial flows of gas from Canada to the US (estimated 107 bcm in 2001).





<u>Demand Response to changes in natural gas prices</u>

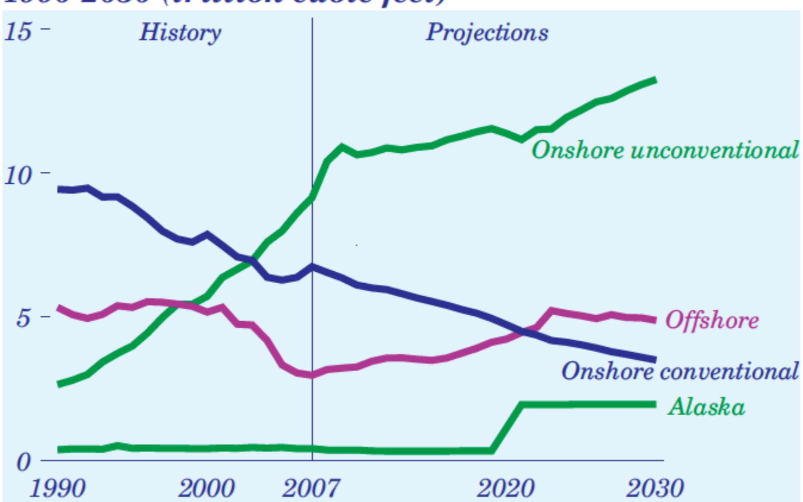
Conventional economic theory tells us that in the long run, consumers will react to prices and what remains for us is explore is whether this happens in the market for natural gas.

As energy prices have risen steadily over the past couple of years, there has been an observed tendency to lower ammonia and methanol output and switches production to sites near cheap sources of gas. However, since the North American prices are not indexed, a supply shock/price spike will decrease consumption, regardless of whether the consumer buy spot prices or fixed price gas. In the case of the latter the consumer will just stop buying if the sport price becomes too high, in the case of the latter the consumers might have to sell back to the market for a profit and thereby interrupting his/her own consumption.

Supply in the US market

The United States have the biggest gas market in world. Proven gas reserves amounted to 7.8 tcm at the beginnings of 2002, which is 4% of world gas reserves.

Figure 66. Natural gas production by source, 1990-2030 (trillion cubic feet)



Below are EIA estimates of natural gas reserves in the United States.

Natural Gas Technically Recoverable Resources

Natural Gas Resource Category (Trillion Cubic Feet)	As of January 1, 2007

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**

Source: Energy Information Administration -

Annual Energy Outlook 2009

The single largest source of U.S. Natural Gas Supply is unconventional production, in particular natural gas in tight sand formations, which is predicted to accounts for 30% of total U.S. production by 2030. Production from shale formations however, is the fasted growing source.

<u>The US Natural Gas Market</u>

The US has a vast network of high-pressure interstate pipelines or trunk lines that carry gas from the major supply areas- notably Mexican Gulf (onshore and offshore), the lower Midwest, the Permian Basin on the Texas/New Mexico border, the San Juan Basin in the southwest if the Rockies- to the main areas of consumption both within the producing regions and in the Northeast, Midwest of California. There are also a number of pipelines linking the principal producing fields in the Western Canada Sedimentary Basin with US markets in California, the Midwest and the Northeast (the Northeast being the largest consuming region). These networks are highly integrated so that gas from producing states in the Gulf region can in principle move just about anywhere in the system. The transmission system includes 270,000 miles of pipelines. With this said, the supply security issue discussed above may not be all that relevant in the case of the US.

The next section is devoted to the study of two phenomena in the US natural gas market: the rise in price and the increase in price volatility. While they are closely related by the underlying causal factors, one need not imply the other.

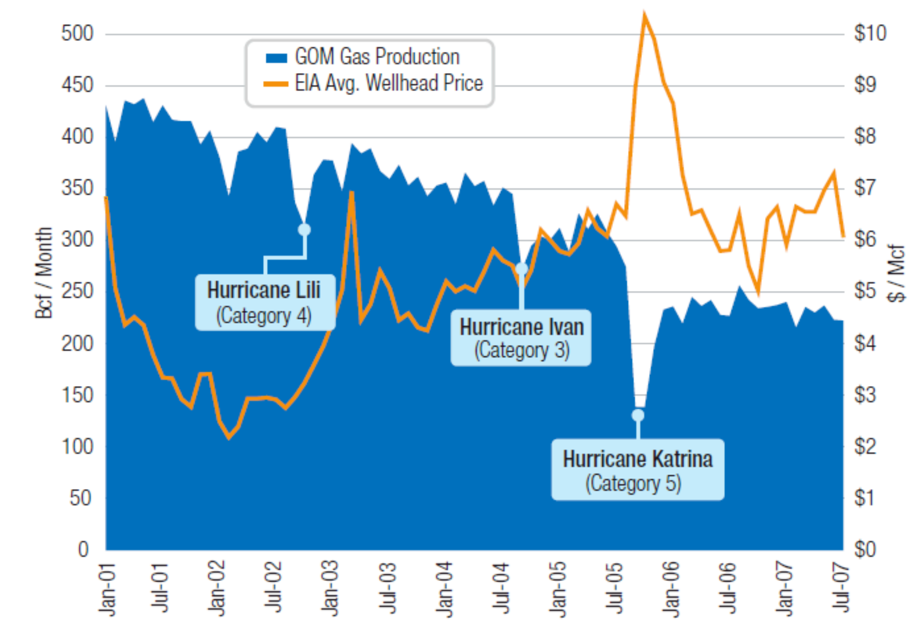
Price increase

The long term equilibrium price for natural gas in the US has been persistently rising during the past 10 years, from approximately $2 per million btu to around $4.50 in 2003. The extent to which this price increase is felt by different sectors is difficult to quantify as we have mentioned earlier, the natural gas market is a segregated one with users facing significantly different prices.

There are a couple of reasons behind this persistent price increase, the most common one being the inflexibility/rigidity of natural gas supply and demand. This brings us back to our discussion about endogenous "features" of natural gas that determines its pricing structure. For one, gas production and transportation require large investment because of difficult geological conditions of extraction and production and transportation considerations. Also, once the project is planned out and its investment funds are committed, the project's carrying capacity is usually fixed, rendering it difficult to keep up with changing demand trends. There is also the issue with time lags. In the US, when gas prices spikes, producers increase their drilling but it usually takes around 18 months before such new drilling translate into additional production capacity. Part of this supply rigidity can also be explained if there are other countries involved in the “gas chain”. In such a case, price signals will not necessarily lead to investment, production…etc[4].

Of course, there are other “exogenous” factors that contribute to this supply rigidity. The latter could be a result of supply restrictions, such as environmental pressures (occurring in 1990s to build power plants that are fueled by natural gas in order to economically comply with new source review regulations introduced in 1970s), difficulty in public land access…etc. Indeed, there are some analysts who argue that regulatory mandates are to blame for the price increase as they have prevented portfolio diversification of energy choices, which leads to markets that do not adapt to unanticipated and changing conditions.

FIGURE 1
GULF OF MEXICO MONTHLY NATURAL GAS PRODUCTION AND WELLHEAD PRICE ($/MCF)



[4] It should be noted that this may not be a good explanation in the case of the US where the imports of natural gas accounts for a mere 1% of total natural gas consumption

The above shows the Gulf of Mexico production trends. As we can see, exogenous factors such natural calamities can be induce producers to cut their supplies (the three dips in production correspond to the three hurricanes). It should also be noted that due to the recent cold weather, a record amount of natural gas has been withdrawn from storage in February, dropping inventories below the five-year maximum for the first time in over a year (see section on storage and pricing). Also, the high cost of replacing natural gas production across all basins has raised the price floor. This is worsened by the gradual reduction in supply from conventional gas basins and the steady increase from unconventional basins. Canada is also cutting its natural gas exports to the US due to the high domestic demand that it is facing. Demand rigidity on the other hand, comes from the inability of some end-consumers of natural gas to switch to a different fuel when gas prices are high (see demand responses).

Interestingly enough, high oil prices may also "allow" gas prices to soar due to competitive fuel switching. This is exacerbated by the fact that the petroleum supply industry tends to favor oil development over that of gas when prices are high, because oil development costs and the lead time to first production are usually less.

<u>Price Volatility</u>

Technological innovations (see appendix) in the discovery and the extraction of natural gas has allowed for a greater proportion of gas reserves to be brought to the surface. For example, marketed production in Wyoming has risen from 3.4 percent of total US output in 1996 to 7.1 percent in 2003. Coupled with technological advances in natural gas drilling however, is the accelerated rate of depletion of newly discovered gas reservoirs (from 21% in the early 2000s to around 30% today). This increase in depletion rate is especially impacting for conventionally produced gas because tight sand gas (which comprises an increasing share of newly discovered gas fields) exhibits a slower depletion rate than conventional wells.

Despite these technological advances however, the price of US natural gas and its volatility are still on the rise (it should be noted that the first does not imply the latter). While it is true that historically, the price of gas has always been extremely volatile (a large part of this is due to its sensitivity to seasonality- more gas is demanded during the winter and less during the summer, this ratio is about 2:1, the ratio is even large for the residential sector 7.4:1), since early 2008, natural gas prices hit the record volatility of 70%.There a few speculations as to why gas prices have become increasingly volatile. But most of them can be reduced to a tightening of supplies and a spiking in demand. The latter has been especially important in the past couple of years due to the sudden surge of “environmental conscience” all around the world (especially among the G20 nations), which is best captured by the agenda of the 2009 Copenhagen Climate Conference.

As price volatility is never desirable for any economic agent, it should be reduced through several means:

1) As price volatility is intimately tied with the level of storage (if the storage capacity is sufficiently large then more gas can be pumped into the market when demand

pressures are putting a strain on supply), improving storage would have reduce the level of volatility faced by US users (see section on "storage).

2) The regional price differentials of natural gas in the US generally reflect the cost of transportation from another region, improving the efficiency of transportation will also reduce the price volatility

In general, commodities with relatively constant supply and relatively variable demand tend to be more price volatile. It can also be observed that the volatile spot prices of natural gas reflect the less developed, price dampening global trade of natural gas. Oil producers on the other hand, have unlimited access to world oil supplies so oil refiners in the US can easily smoothen out price spikes by importing oil from other countries.

An increase in the level of global trade may reduce price volatility of US natural gas. Although it is possible to import LNG from abroad (in fact we do see increased marginal supplies from abroad), it can also make US dependent on insecure foreign supply (like the oil case), and is therefore a legitimate area of concern. While this is something that is often hotly debated by politicians and economists alike, the fact that natural gas reserves are more widely dispersed in the world than that of oil source is often overlooked. This is important as it lessens the danger of the US being dependent on a "sole source of energy".

With the development of many new LNG terminals within the US, interregional pipelines, LNG swaps (allowing for spot and short term contracts) we are beginning to witness to beginning of a global natural gas market in which the US will play a significant role.

Sara Sayeed, Marta Ryvak, Fang-Yu Liang, Nick Zhao

Conclusions

It seems that in order to stabilize prices, the US natural gas market must increase their "safety valve" of natural gas supply. Whether this should be done by increasing domestic supply, or importing from foreign sources is something to be determined. There is of course, always the option of government intervention through the use or tax/subsidies and price caps. The case is weaker for the latter intervention due to California's experience in the Western Energy Crisis. Recently, the Obama Administration has also proposed to lower energy subsidies, especially in the oil industry, with the aim to lower greenhouse gas emissions. This may in fact increase the natural gas's market share in the energy industry as oil prices rise.

Some analysts have also argued that the abundance of coal in the US (according to the EIA, the US still has 250 years of domestic supplies) justified the compensatory role of coal during the time tightening gas supplies. It should not noted however, that although existing coal fired plants are still cheaper for base load production than bringing new gas turbines, many coal plants will reach the end of their useful lives over the next two decades and gas turbines will have a strong advantage when new installations are being considered.

As a forecast for 2010, Bloomberg has predicted that natural gas prices in the US will continue to drop. Some analysts have shown that this depressing trend of natural gas prices does not have much to do with the increase in domestic output, which has remained resilient and fell on a monthly basis since the last quarters of 2009. Instead, this downward trend seems to be caused by a decrease in domestic demand[5]. Of course, this does not mean that the US is using less natural gas now. On the contrary, they are using more natural gas than ever, and we predict that the volume of natural gas that will be used in the foreseeable future is even larger due to President Obama's vow to cut U.S greenhouse gas emissions by 17% at the Copenhagen Climate Conference[6]. The root of this almost twofold decrease in domestic gas demand then is caused by an increase in volume of LNG imports.

Natural Gas Storage

Overview

Natural gas is extracted from gas producing fields, where the extraction rate is nearly constant overtime. Because natural gas is so essential to people's lives, it is very important to ensure an adequate supply of it at all time. The industry cannot produce natural gas in labs to address the possible shortages. Therefore, storage of natural gas, as in commodities, is needed to manage fluctuations in supply and demand.

When demand of gas is low, such as in summer, excess supply of natural gas can be saved into storage rather than disposed, causing pollution. In turn, when the demand rises during wintertime, the stored gas can be withdrawn to meet the rising need. In addition, gas storage also addresses short-term fluctuations in the gas market that are unpredictable as in natural disasters and gas field malfunctions. The storage methods serve as a buffer between

[5] "Russian Bear Menaces U.S. Gas Prices" Wall Street Journal, Dec 1 2009

[6] "Top 5 Issues at the Copenhagen Climate Conference" US News, Jan 19 2010

transportation and distribution to ensure an adequate supply of natural at all times and at all locations.

Other subordinate uses of storage include balancing the flow in the pipeline system; leveling the cost of natural gas by controlling the supply and make the its fluctuation more predictable; supplying gas for the power plants that operate all year long; commercially storing gas when price is low and selling it when price is high; and meeting various regulatory obligations.

To measure and grade the quality of storage, we need to know its measurements. Total gas storage capacity refers to how much natural gas the facility holds under optimal condition. Generally, the bigger the facility, the greater the capacity becomes. This is not to be confused with total storage, which is the amount of gas available at particular times. Base gas is kept permanently in the facility in order to maintain its pressure; some facilities require lower base gas volume than others, which makes them economical. Base gas is different from base load capacity, which is the minimum amount of gas stored to meet seasonal increase in demand.

Working gas capacity is total storage subtracted from the base gas requirement; it is total gas deliverable to the outside market. The greater the working gas volume, the more useful the facility is to the end users. On the other hand, in facilities with high base gas to total capacity ratio, working gas is therefore expected to be low, making them less viable. But the construction and maintenance costs often offset the benefit of high working gas volume.

Deliverability is a rate that explains how much gas the facility withdraws daily. It is measured in millions of cubic feet per day or MMcf/day. However, deliverability has little to do with the type of facility the gas is stored. It depends more on the total storage at particular time, working gas to base gas ratio, pressure within the facility, compression capability available, and others. Therefore, the higher the storage, the faster the deliver rate tends to be.

Less importantly is the injection rate that accounts for the speed of transferring gas into the facility. It is also measure in MMcf/day. As a direct reverse of the delivery process, the injection is faster when storage and working gas are low.

Distribution of natural gas storages in the U.S.:

In the United States, working gas capacity is lowest in April and highest in November. In between April and November, the demand of gas is low where excessive gas injects into storage. In between November and April, the consumption is high where the stored gas withdraws and exhausts. Therefore, a cycle in natural gas storage is exactly a year.

Also in the United States, there are 120 gas storage operators, with a working gas capacity of nearly four trillion cubic feet. However, the distribution of these operators is quite geographically uneven. Most operators are located in the northeastern side of the country and the gulf coast region. There are very few storage facilities located on the western coast and mountain regions. However, this distribution is explicable in several ways. The northeastern part of the country tends to experience greater fluctuations in temperatures and colder winters than the rest of the country; this fact indicates higher demand in these regions. There are also abundance depleted, recyclable reservoirs in these regions to convert to gas storages. By contrast, the western United States enjoys generally warmer weather all year long, with lower demand in natural gas. The mountain regions have less population, which indicates less demand than the populous regions. The gulf regions, though with similarly low demand, are big producers and exporters of natural gas, where storages are also needed to balance the market.

Storage facilities:

Although natural gas storages serve the same purposes, there are many methods to build them, with each having its advantages and disadvantages. Primarily, stored gas is held in underground formations such as depleted oil or gas reservoirs (the most common), in natural aquifers, or in cavities created in large underground salt deposits.

In the United States, gas is most commonly stored in depleted natural gas or oil fields near the center of consumption. The great advantage of the conversion field is its wide availability all around the country. These formations offer vast spaces that are geologically capable of holding natural gas in great volumes. In addition, the old reservoirs provide left over equipments and extraction networks that can be reused to save the cost of construction. These include existing wells, gathering systems, and pipeline connections. The conversion also helps recycle the old fields rather than abandoning them, which is an environmental benefit. In general, this type of facility is the cheapest to construct and maintain. However, some reservoirs require greater base gas volume and experience difficulties in injection and delivery. Also, depleted fields are rare in some rural areas.

Another common method is the conversion of aquifers found primarily in Midwestern United States. An aquifer may be easily available, however, only certain modified aquifers that has rock formation overlaid with an impermeable cap rock can be used for storage. There also needs extra monitoring effort on aquifers. Aquifers also take high base gas volume, at about 70%. Still, aquifers are better alternatives when there is an active water drive that enhances deliverability and when depleted reservoirs are not present.

A third method is the use of salt caverns. They are commonly found in the gulf of the United States. The cavern is created using fresh water to dissolve cavities in the salt formation, which forms large quantities of brine. Some great advantages of salt caverns are high withdrawal and injection rates and low base gas requirements, at around 25%. However, the construction of the cavern can be more expensive than depleted field conversions, especially in regions outside of the gulf coast. The brines are difficult to dispose and cause environmental damages.

Rarely, abandoned mines and hard-rock cavern are used to store natural gas. These facilities may cost less overall but are hard to find. The natural gas can also be stored in tanks as liquefied natural gas (LNG). LNG condenses the gas and allows it to become portable.

Gas is injected and withdrawn from these storages using the same type of well drilling and production equipment of natural gas fields. The capacity of storage, however, tends to decline rapidly among these storages. On average, gas storage wells in the United States lose about 5 percent of their ability to inject and withdraw gas each year. This problem is caused by the buildup of calcium carbonate and organic residue that clog the openings.

The costs of storage:

The construction or conversion of a natural gas facility can be extremely expensive. For example, the development cost of a salt cavern ranges from 10 to 25 millions of dollars per billion cubic feet of working gas capacity. The cost of construction escalates with the type of facility (salt cavern is the most expensive), the difficulty in locating and testing a storage site, the complicated geology of the site, the power needed to operate the facility, the distance from the consumption center, regulatory restriction, and various environmental issues.

The major cost in recycling depleted reservoirs and aquifers are the base gas injection, which account for more than 50% of the total capacity. The major costs in salt caverns are leaching and brine disposal, which are both expensive and polluting.

Other costs include the service costs to both deliver gas from and to maintain the facility. They can be as expensive as over 10 millions dollars annually per facility. They include the cost of using interstate pipelines, tariffs, electricity, and storage services.

Lastly, there are always those per unit costs associated with injection of natural gas, its storage, its capacity depletion through leakages, and its extraction. Again, these costs can cost millions and vary based on the nature of the facilities.

Regulation and ownership in the U.S.:

There are about 80 corporate entities that operate the 400 + storages across the U.S. The entities are either subject to the regulation of the state they operate in, or subject to the jurisdiction of the Federal Energy Regulatory Commission, the FERC.

Interstate and intrastate pipeline companies own most storages. These companies use storages to perform load balancing and supply management for their pipelines. They also lease their storages to others in the industry. However, interstate companies rarely serve the end users directly.

The local distribution companies (LDC) directly serve the customers over certain regions. These companies are owned by either private investors or the local governments. They control the flow of gas through the pipelines to individual households. Before 1992, natural gas storage was a product sold by pipelines to these LDCs; it was heavily regulated to meet the transportation and distribution needs.

After the market deregulation through FERC Order 636, storages become available to anyone for commercial purposes. In other words, after 1992, many storage facilities have become profitable businesses where the private owners inject gas when price is low and deliver it when the price is high. This deregulation gave greater flexibility to storage managements in recent years.

Ways to improve storage:

As the demand of natural gas increases over the years, it is important for us to address the possibility of gas shortage in the near future. Also, we need to figure out a way to make natural gas storage more environmentally compatible and economically efficient.

One existing proposal from the Department of Energy is to somehow to make the facility to chill the natural gas and reduce its volume, which reduces the burdens of constructing a large storage and increases the total capacity. This proposal would work extreme well on salt caverns that are very expensive to construct due to disposing of the leached brine; this would make salt caverns more affordable to areas outside of the gulf coast.

To chill, one can freeze the natural gas in the presence of water, and turn it into hydrates. The hydrates store natural gas in exceptionally large capacity. It is even proposed that an over 100 cubic feet of natural gas can be store in one single cubic foot of hydrate. We can such create a better storage by making mini storages.

Also, we can expand storages by trying to convert other formations into gas containers. This includes limestone, granite, and sandstone formations that are found at random locations across the country. These can become great substitutes for the locals wherever the three main formations are absent.

Lastly, we may further invest in privately owned, portable home natural gas tanks. We can liquidize the natural gas immediately from the gas field and store it into steel tanks. These containers can serve the users at anytime they want. They can take the tanks on vocations and use them wherever the access to gas is otherwise unavailable.

Investment in natural gas:

Investments are needed as the demand for natural gas continues to rise. The production of natural gas has been nearly flat for the past decade. Therefore, we need to find ways to stimulate and increase this rate.

Natural gas often comes in competition with investment in oil and coal. There are many advantages in investing in natural gas over oil and coal. First, the price of natural gas is much lower than that of oil at about 1 to 8, yet it is rising steadily. Next, the combustion of natural gas is cleaner to the air than the combustions of oil and coal. This makes natural gas politically and environmentally friendlier. Natural gas is also lighter than oil and coal, which bears less transportation cost. Lastly, there is always a demand in natural gas as it is essential for households to combat winter, whereas oil and coals are necessary but not essential for livelihood.

Generally, there are several areas of investment in the natural gas industry. The investor can invest in the search and exploration of producing site; invest in the construction of the site; invest in the production of natural gas; invest in pipelines and transportation of natural gas; invest in the storage facilities and others.

One possible new area of investment is in fuel cells. The cells extract hydrogen from the gas and combine it with oxygen to produce water, electricity and heat. They are efficient and convert 60% of the energy in gas directly into electricity. These fuel cells become generators to power up cars and provide energy sources to households and factories. If this technology is further invested, natural gas powered fuel cells may lead to an energy system run on emission free, non-depleting hydrogen.

A second new area of investment is in gas made from biomass. The mass decays and produces methane overtime. We can invest in the capture of methane gas produced by landfill and sewage--this investment will not only provides a cheaper source for natural gas, but also prevents the spread of polluting methane.

Why natural gas storage may be cheaper than oil and coal storages

First of all, as indicated, natural gas is much more cleaner to the environment and produces half time less CO2 than oil or coal. With that being said, the risk of natural gas leakage during storage is far less than the spill of oil. Oil spill causes extreme environmental damage especially to organism in water; in addition, it is nearly impossible to remove the spillage.

Leaked natural gas, though still somewhat polluting, vaporizes and disappears quickly in the atmosphere.

Coals contain the compound marcasite that frequently risks spontaneous fire accidents when in storage. The fire can ignite a majority of coals in storage at once. It will then penetrate the surface and create devastating wildfire; even not, the CO2 burning fire would cause great pollution. By contrast, natural gas would not combust on its own.

Secondly, natural gas is stored in underground facilities that can hold a great volume at a time. Due to weight and volume, natural gas storage is cheaper than the storages of liquid and mineral in general. Whereas natural gas can be stored in a great variety of facilities, the means to store oil and coal are much restricted.

Crude oil is generally stored and imported in medium sized tanks and pipes. It cannot be sealed within underground formation, as it is a dissolvable liquid substance. Such, oil in storage is much restricted in volume. Oil is far more difficult to transport than natural gas that is much lighter. Crude oil also requires more labor to inject and pump from the tanks than it is for natural gas through pipelines.

Similarly, coal storage is more expensive than natural gas in that coals have to be manually stored into and delivered from the storage using carts or other vehicles.

Also, we should store more gas than oil and coal because the unit price of natural gas is cheaper than the prices of the latter two. Such, the demand for natural gas is rising much faster than that of coal and oil. This means that in the near future people will start using more gas, whereby investments in the storage of the gas becomes increasingly economically rewarding.

Natural Gas Political Issues/Regulation

What People Are Doing

The natural gas case is gaining traction in Washington, D.C. Oklahoma and Pennsylvania representatives Dan Boren and Tim Murphey have created a Congressional Natural Gas Caucus to help raise public awareness of natural gas. They note that natural gas is produced in 32 states and the industry provides employment for approximately 3 million people in the United States. These numbers suggest that 32 governors, 64 senators, and 324 Congress members from natural gas producing states may support the effort to boost the industry's profile.

Amy Myers Jaffe, energy expert at Rice University, points out that all the benefits to the coal industry provided by the Waxman-Markey bill recently passed make the global warming cause even worse off, what with the amount of carbon emissions produced by coal. She stated that grandfathering coal is "worse than doing nothing". If it wasn't for the political boosts and benefits granted to the coal industry, natural gas would be more widely used than coal because it is becoming even cheaper and emits half as much carbon (http://blogs.ft.com/energy-source/2009/10/08/us-natural-gas-gaining-traction-in-dc/).

Boxer-Kerry Climate Bill

The Boxer-Kerry climate bill, proposed by Barbara Boxer and John Kerry, is an ambitious plan to reduce carbon emissions by 20% by the year 2020. This plan includes strong incentives for the natural gas industry, including rewarding companies that switch from power sources with higher carbon emissions to those that emit less CO_2, such as gas. The bill was praised by Senator Mary Landrieu – she stated that any move towards increasing natural gas use is a very smart thing to do and that leaders are beginning to hear more from different natural gas-producing regions of the country on the abundance of natural gas within our borders. Landrieu was one of nine senators that sent a letter to Barbara Boxer asking for more incentives for the natural gas industry. Producers of natural gas have also been aggressively increasing their lobbying efforts to ask for more natural gas incentives and have begun to gain more support. Natural gas plants may be eligible for the incentives as a fuel that produces half as much carbon dioxide as coal and a third less than oil, as well as a backup source for solar, wind, and other renewable energy sources (http://www.eenews.net/public/EEDaily/2009/09/30/1).

Policy

- Regulation is geared to promoting competition and investment
- Governments are changing policies to stimulate the long-term investment needed in the NG industry
- Examples include EU Commission's efforts to stimulate competition between suppliers, elimination of destination clauses on gas delivered to the EU, and the Second Gas Derivative
- Canada and US are implementing regulation that encourages more exploration and production, and US passed legislation to encourage LNG imports

Reasons

- The transportation sector is 70% of total US oil consumption. To significantly reduce US foreign oil imports the US must reduce oil (gasoline) consumption in the transportation sector.
- The only US domestic fuel capable of being scaled up to significantly reduce oil consumption in the transportation sector over the next 5-10 years is natural gas.
- Natural gas vehicles emit 20% less CO_2 than do gasoline powered internal combustion engines and none of the toxic particulates.
- Natural gas reserves in the US are abundant and can power US home heating, industrial, electrical generation, and transportation sectors for decades into the future.
- Vast US natural gas reserves and the nation's 2.2 million mile natural gas pipeline grid are the best weapons in the war on foreign oil imports.
- Natural gas is an ideal bridge to a renewable energy future. Natural gas electrical generation is the preferred backup power supply for intermittent wind and solar energy.
- Natural gas electrical generators are more efficient and emit 50% less CO_2 than coal-fired plants and none of coal's very toxic particulate waste and ash.
- "Clean coal" is an oxymoron and a myth.
- Environmental purists who support only electric vehicles over the short term are shooting themselves in the foot by increasing demand on coal-fired electrical generation for recharging.
- Much of the natural gas infrastructure could be used by the future hydrogen energy based economy.

- The world economy is now riding a peak oil driven yo-yo. The consequences for the US, which uses 25% of worldwide oil supply and imports 65% of it, will be grave.
- The only solution to the severe economic, environmental, and national security issues facing the US is a **strategic, long-term, comprehensive energy policy to reduce foreign oil imports**. In the short to mid-term, US energy policy should be centered on using US produced natural gas for transportation. Such an energy policy was published here on SA.

Not everyone agrees with all of these bullets. However, after much constructive debate in SA's comment section, no evidence was presented that any other energy policy can significantly reduce foreign oil imports (say 5-7 million barrels a day) over the next 5 years.

So, what now? For those of us who believe a natural gas centric energy policy should be an urgent and critical priority for America's future prosperity, how can we make it happen?

President Obama and Energy Secretary Chu obviously do not have reducing foreign oil imports high on their list of priorities. This is evident by the lack of legislation presented to effectively and significantly move the US away from gasoline powered automobiles. The electric car solution doesn't work over the short term because EVs would be charged by coal-fired power plants. That is not an acceptable strategy. Equally disturbing is Obama and Chu repeating their oxymoronic "clean coal" mantra so often they have begun to believe it is actually possible. It is not. More worrisome is Energy Secretary Chu's recent comment that he is "agnostic" about natural gas transportation. Clearly then, natural gas transportation supporters cannot rely on the Obama administration for a strategic energy policy or even a level playing field for natural gas vis-à-vis coal and oil. We must therefore accept the current political climate and take matters into our own hands. We must go straight to the American people with political activism, policy initiatives, while pressuring automobile manufacturers to deliver NGVs and refueling solutions. But exactly how should we proceed?

Political Initiatives

- **Support H.R. 1835 – Legislation for Nat Gas Transportation**

HR 1835 is a bi-partisan bill containing robust support for natural gas transportation initiatives. Everyone who works for an American company that makes automobiles or natural gas compressors or industrial equipment should support this bill. Everyone who works in the natural gas production or energy services businesses should support this bill. Every farmer or landowner that has natural gas on his property should support this bill. Every American who is tired of funding both sides of the "war on terror" should support this bill. And every environmentalist that wants to breathe cleaner air and view clearer skies should support this bill. Call or write (letters with stamps, not email) your elected officials. Let his or her know you want them to support this bill and that you will be watching energy policy voting very carefully.

http://seekingalpha.com/article/135758-making-natural-gas-transportation-a-reality

Policy questions

It seems that in order to stabilize prices, the US natural gas market must increase their "safety valve" of natural gas supply. Whether this should be done by increasing domestic supply (either by improving storage capacity, exploring

-Should the US really reduce coal use although she still has 250 years of domestic supply (50% of electricity generation)

-Although existing coal fired plants are still cheaper for baseload production than bringing new gas turbines, many coal plants will reach the end of their useful lives over the next two decades and gas turbines will have a strong advantage when new installations are being considered

-pass energy bill legislation that continues the trend to pressure more use of natural gas even with higher prices?

-Challenges posed by transporting gas in its cryogenic form as a liquid coupled with environmental and safety concerns that limited the imports of LNG in US to a mere 1% of US gas supply. So in order to access the world natural gas reserves there needs to be an expansion of LNG terminal import capacity and development of newer offshore regasification technologies As the technology of liquefaction of shipping of LNG improves, so does the possibility of US importing more natural gas from abroad to stabilize its price fluctuations.

-While the North American market is still regional, new global developments in LNG transportation is increasing the possibility of a global gas market

Sara Sayeed, Marta Ryvak, Fang-Yu Liang, Nick Zhao

-moving gas between regions is becoming increasingly possible due to the introduction of LNG cargoes, interregional pipelines, and LNG swaps which allows for spot and short term contracts, encouraging speculative ventures and new entrants into the market

Natural Gas – Transport and Distribution Costs

Increased use of natural gas is a favorable alternative to many other sources of fuel for a number of reasons, and can result in significantly lower carbon emissions, lower costs, and lower foreign energy source dependency. With abundant domestic reserves, this can be possible without increased natural gas drilling in new locations of the discovery of fresh reserves. Investing in improving the efficiency of the systems currently in place can be significantly more cost-effective and achieved much more quickly than increasing drilling and supplies. This can result in a relatively speedy reduction in costs for end users.

Natural gas transport involves a network of interstate (across state boundaries) and intrastate (within a particular state) pipelines that carry gas from its area of production to end users. There are three main systems within the network: the gathering system, the interstate network, and the distribution system. The gathering system is a set of low-pressure, low-diameter pipelines that transport raw natural gas to processing plants, while the distribution system transports ready-to-use gas to local regions. The diameter of these pipes ranges from 6 to 48 inches, and during distribution gas travels at pressures from 200 to 1500 pounds per square inch. This reduces the amount of natural gas being transported by up to 600 times. Compressor stations are placed at 40-100 mile intervals along interstate pipelines to ensure the gas remains pressurized, powered by small amounts of the gas being transported (http://www.naturalgas.org/naturalgas/transport.asp).

Transportation and storage of natural gas are the major difficulties of natural gas use due to the low density of gas. Natural gas pipelines are economical, but many in North America are close to reaching capacity and thus leave politicians worrying about potential shortages. In addition, pipeline transport is not practical for overseas transport, and is preferred only for distances 2000km overseas and twice that over land. LNG carriers are used to carry liquefied natural gas (LNG) overseas, and tank truckers are used top transport liquefied or compressed natural gas (CNG) over shorter distances. LNG transport requires the building of liquification plants, which can be a capital-intensive process.

Compressed natural gas is natural gas that is stored at pressure. With increased pressure a larger volume of gas can be contained and transported within a unit of space. CNG is necessary for pipeline transport. Refrigerating CNG reduces the density even further and allows for greater transport volumes.

CNG transport requires generally over 200 bars of pressure, though compressors and decompression equipment may be cheaper and thus more economical for smaller unit sizes. The downside of CNG transportation is the investment into and operating costs of CNG carriers. Natural gas is stored underground in depleted gas reservoirs, wells, or in tanks as LNG. Gas is injected into these storage facilities during times of low demand and extracted when demand increases. (Wikipedia).

Flexibility and Capital Investment

Natural gas electric generation plants can range in size from larger to smaller scale microturbines, whereas coal fired and nuclear powered plants are not as flexible and perform only large-scale generation, forcing them to produce more electricity to be economically efficient. Since the demand for electricity is expected to rise modestly in the coming decades, electricity suppliers face a tough decision in determining whether making the large capital investment necessary for coal or nuclear power generating plants. Lower capital costs are required for natural gas-powered facilities, with lower construction and lead times making it more practical to increase generational capacity as demand continues to grow.

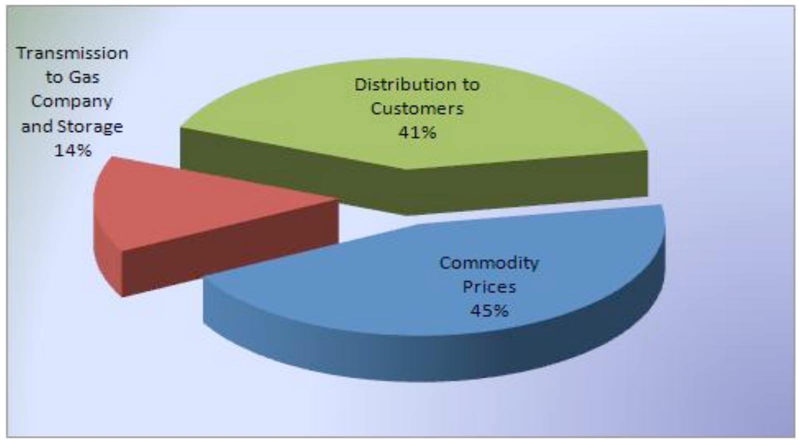
In addition, natural gas powered generation plants are operationally flexible and used to meet changing short term peak demands, having the ability to be easily turned on and off quickly to respond to whether-related or other short-term demand fluctuations. Since neither coal nor nuclear generation plants demonstrate this flexibility, natural gas powered generators stand as an attractive operationally efficient option to manage demand volatility.

Another cost issue with regard to natural gas transport and distribution is pipeline infrastructure. The limited capacity of intrastate and interstate pipeline systems in effect creates a ceiling on how much natural gas can be delivered to the market. Current pipeline infrastructure is significant (there are currently 220,000 miles of pipeline in North America, though natural gas pipeline companies must commit capital to continually expand this infrastructure to be able to meet projected demands. Thus far, the industry has responded with relatively rapid expansion of infrastructure to stay in line with growing supplies, discovery of new resources, and demand growth, with 5,000 miles of pipeline completed in the past three years.

Distribution of Natural Gas and Associated Costs

Distribution of natural gas delivers the final product to end users, which include large industrial, commercial and electric generation customers as well as smaller individual users. Larger consumers receive natural gas directly from interstate and intrastate pipelines, while smaller users receive it from local distribution companies (LDCs), which typically take ownership of the gas once it is received and are located according to geographic regions to serve as delivery points to local users. LDCs are either investor-owned or the property of local governments, and transport gas from delivery points along the larger interstate or intrastate pipeline system and into miles of small-diameter local distribution pipe, of which there is an estimated one million-plus miles in the United States. The delivery points to LCDs are called citygates, and serve as important points for determining the market price of natural gas based on the supply and demand flow.

Due to the extensive infrastructure required in the delivery of natural gas across the country, distribution costs account for a bulk of natural gas costs for smaller consumers receiving gas through LCDs. While larger users of natural gas such as industrial consumers can take advantage of lower unit costs through the distribution or large volumes through wide-diameter pipes, distribution companies face the expenses and inefficiencies of delivering small amounts of gas to small volume gas consumer to many different geographic locations. Because of this, the typical small volume consumer faces a natural as bill that is composed of up to 47% of distribution costs, as estimated by the EIA, while physical commodity prices make up approximately 34 % of the bill and transmission and storage costs comprise 19 percent. Traditionally, rigid steel pipe was used to construct distribution networks. However, new technology is allowing the use of flexible plastic and corrugated stainless steel tubing in place of rigid steel pipe. These new types of tubing allow cost reduction and installation flexibility for both local distribution companies and natural gas consumers.



Components of Residential Natural Gas Prices

(Click Image to Enlarge)

Source: Energy Information Administration

Another innovation in the distribution of natural gas is the use of electronic meter-reading systems. The natural gas that is consumed by any one customer is measured by on-site meters, which essentially keep track of the volume of natural gas consumed at that location. Traditionally, in order to bill customers correctly, meter-reading personnel had to be dispatched to record these volumes. However, new electronic meter-reading systems are capable of transmitting this information directly to the local distribution company. This results in cost savings for the LDC, which are in turn passed along to customers. The installation of natural gas distribution pipe requires the same process as for larger pipelines: the excavation of trenches into which the pipe is laid. However, new trenching techniques are allowing for the installation of distribution pipe with less impact on the above ground surroundings. Guided drilling systems are used to excavate an underground hole in which the pipe may be inserted, and can lead to significant excavation and restoration savings. This is particularly important in crowded urban settings and scenic rural environments, where the installation of natural gas distribution pipe can be a major inconvenience for residents and business owners.

Supervisory control and data acquisition (SCADA) systems, similar to those used by large pipeline companies, are also used by local distribution companies. These systems can assimilate gas flow control and measurement with other accounting, billing, and contract systems to provide a comprehensive measurement and control system for the LDC. This allows accurate, timely information on the status of the distribution network to be used by the LDC to ensure efficient and effective service at all times.

http://www.naturalgas.org/naturalgas/distribution.asp

Transport

- Gas is transported through pipelines as LNG
- Gas is transported from the well-head to the burner tip in 2 ways: through pipelines or in the form of LNG – both ways are expensive and involve long construction times
- A considerable period is needed to pay back initial investment
- With high natural gas prices, there is more incentive for producers to commit capital

- Pipelines are more cost-effective over short distances, though they tie the consumer to the producer which creates a negotiating positions and involves a level of trust
- LNG is gas that has been cooled to -161 degrees C in a liquification train
- AA plant starts with one or two trains, and once these trains have shown to be successful technically and commercially, more trains can be added at a lower marginal cost – gas is transported in ships and returned to its normal state upon delivery in a re-gasification terminal
- High capital costs of LNG production and transport have produced a business model that involves long-term take-or-pay purchase obligations, agreed far in advance of plant construction – cost of LNG production is low enough for it to be globally competitive
- LNG destination can be changed easily and rerouted to the market with the highest price, while pipeline-transported gas is not as flexible

<u>Transport Costs of Oil and Coal</u>

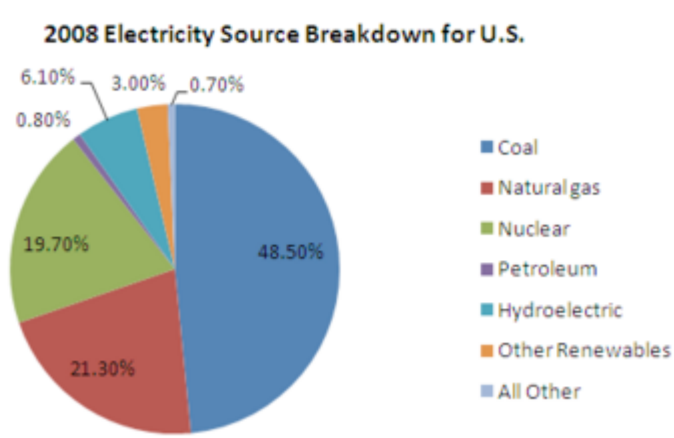
There exist many threats to the transport of oil when compared to natural gas, and therefore higher costs. One major concern is that because much U.S. oil is imported and many of the oil tankers and pipelines flow through some of the most volatile regions of the world, a national security disruption or international conflict can have significant impacts on the price of the fuel.

For instance, 40% of the world's oil flows through thousands of miles of pipelines often in hazardous areas across the globe, and a puncture to a pipeline can deem it non-operational.

Because of the length of these pipelines, they are difficult to protect, and insurance premiums have been rising, and are thus just as vulnerable as tankers.

Martitime insurers have begun to raise rates for tankers in risky waters – for example, premiums for tankers passing through Yemeni waters tripled since the attack in Yemen. For a tanker with a cargo of two million oil barrels, the rate jumped from $150,000 to $450,000, consequently adding 15 cents to the final delivery cost of oil – and this only includes the insurance for the ship and not the cargo on board. The rise of terrorist attacks and other disruptions will increase the costs of protecting tankers, pipelines and oil terminals and be reflected in the final price of oil.

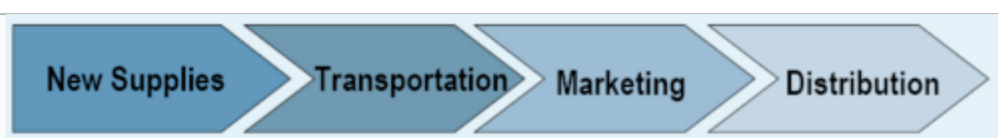
In addition, since more heavy oil is being pumped rather than lighter crude, the fact that heavier crude flows more slowly though pipelines reduces the volume being transported, making it more expensive to transport. To try to speed up the oil flow, oil companies sometimes attempt to dilute it or heat it, techniques which can be expensive and complex.



Power Generation Costs for Various Energy Sources in 2008[21]			
	Fixed Cost (cents/kWh)	**Variable Cost (cents/kWh)**	**Total Cost (cents/kWh)**
Coal	4.1	3.3	7.4
Natural gas	2.8	7.8	10.6
Nuclear	8.0	0.8	8.8
Wind	8.2	0.0	8.2

Energy Return by Source in 2008[22]	
	Energy return on Energy Invested
Coal-fired power plant	2.5
Nuclear power	4.5
Hydroelectric power	10
Wind power	35
Natural gas	10.3

Economics of Natural Gas



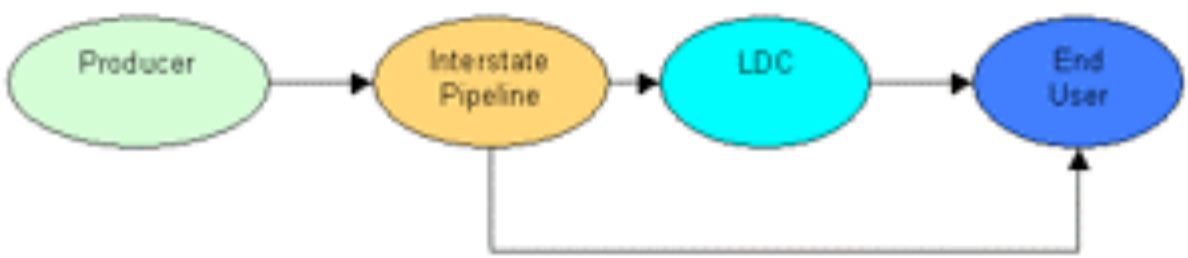
Natural Gas Value Chain

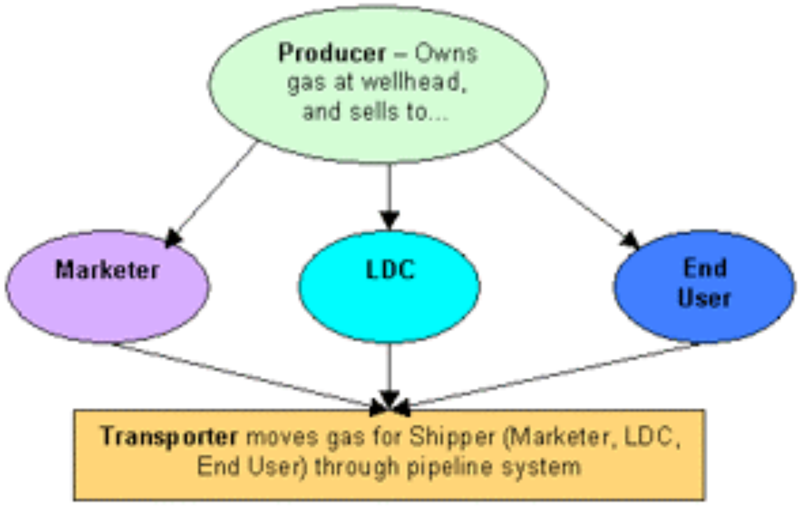
The natural gas value chain is similar to those of other fossil fuels - exploration & production, processing, transportation, additional processing, marketing/distribution, and ultimately, end user delivery. The industry has a natural monopoly because of high capital costs of pipelines, problems with storage and high levels of regulation, though natural gas has benefited from deregulation.

- Deregulation has been a boon to the natural gas industry, encouraging innovation and reliability of supply
- Drivers of the end-user price of natural gas are two-fold:
- 1) The raw fuel costs account for about 60% of final costs
- 2) Transmission and distribution costs account for 40%
- Raw fuel price is market determined, but is driven by market demand and both current and future supply
- Natural gas is difficult to transport and to store, limiting short-term flexibility of supply in response to demand shocks
- Predominant method of transportation in North America is via natural gas pipelines
- Increasingly popular method is Liquefied Natural Gas (LNG), which enables gas to be shipped overseas in tankers
- Both require major investments to expand and develop
- Need major investment in deep-water, sheltered ports to harbor LNG tankers and in liquefaction and gasification plants on both ends of transport route-- as of December

2008, the U.S. had only 8 LNG terminals, but plans to nearly double capacity over the next 3-5 years

- The state of storage capacity and technology has a significant impact on natural gas prices in both the short-term (access to reserves) and the long-term (as increased storage capacity gives opportunity to build up more substantial reserves of easily accessible natural gas)
- Although existing coal fired plants are still cheaper for baseload production than bringing new gas turbines, many coal plants will reach the end of their useful lives over the next two decades and gas turbines will have a strong advantage when new installations are being considered





(naturalgas.org)

Source for above information:

http://www.resourceinvestor.com/News/2009/4/Pages/What-is-the-breakeven-price-for-natural-gas-producers.aspx

Transport

- Gas is transported through pipelines as LNG
- Gas is transported from the well-head to the burner tip in 2 ways: through pipelines or in the form of LNG – both ways are expensive and involve long construction times
- A considerable period is needed to pay back initial investment
- With high natural gas prices, there is more incentive for producers to commit capital
- Pipelines are more cost-effective over short distances, though they tie the consumer to the producer which creates a negotiating positions and involves a level of trust

- LNG is gas that has been cooled to -161 degrees C in a liquification train
- AA plant starts with one or two trains, and once these trains have shown to be successful technically and commercially, more trains can be added at a lower marginal cost – gas is transported in ships and returned to its normal state upon delivery in a re-gasification terminal
- High capital costs of LNG production and transport have produced a business model that involves long-term take-or-pay purchase obligations, agreed far in advance of plant construction – cost of LNG production is low enough for it to be globally competitive
- LNG destination can be changed easily and rerouted to the market with the highest price, while pipeline-transported gas is not as flexible
- Though building out infrastructure has high initial costs, it will cut costs in the long run and be environmentally cleaner
- Oil transport faces threats and major price fluctuations because it is imported
- Coal transport is done primarily by train and is expensive and high in carbon emissions

Investment is Needed – Past Projects Have Shown Success

- Example: US is leading the charge - operations in Pennsylvania and Texas have already been sufficient to cut US imports of liquefied natural gas (LGN) from Trinidad and Qatar to almost nil, with knock-on effects for the global gas market – and crude oil. It is one reason why spot prices for some LNG deliveries have dropped to 50pc of pipeline contracts

Compare to Costs of Coal and Oil Transport

Cost Estimate Breakdown:

From wellhead to pipeline grid: $.30

From grid to processing plant: $.50

Processing and compression: $.90

Royalties: $.70

Operating costs: $.20

Interest on debt: $.50

Finding, development and acquisition: $2.00

(http://www.resourceinvestor.com/News/2009/4/Pages/What-is-the-breakeven-price-for-natural-gas-producers.aspx)

The pricing information above is based on interviews with management from a Canadian natural gas company, but the process is very similar in the United States. These conservative pricing estimates show that the break-even for natural gas companies is near $5 for low-cost producers (for $3.40/mcf gas). Transport costs alone make up $.80 of total costs, and this cost rises significantly with further distance between wellhead and grid and between grids to processing plant. Finding, development, and acquisition, often termed FD&A, also makes up a significant portion of costs, and this area in particular is in need of significant investment if drilling natural gas is to be an attractive potential investment.

The transport of natural gas is much cheaper since the primary transport method is via pipeline across domestic regions. The abundance of natural gas within the United States thus allows for cheaper transport costs of CNG within domestic borders, whereas the transport costs of oil are much higher and have high volatility due to costly and time-consuming transport across long distances via ships.

The chart below summarizes the break-even estimates for oil in different oil-producing countries. It is clear that since the break-even points are much lower in the oil industry than in the natural gas industry, oil is currently a much more profitable investment area, and will continue to be so unless incentives for investment into natural gas are increased. (http://seekingalpha.com/article/58322-oil-price-predictions-and-break-even-prices).

GCC Oil Break-Even Prices July, 2006	
	US$/Barrel
Bahrain	40
Kuwait	17
Saudi Arabia	30
U.A.E.	25
Oman	40
Qatar	30
GCC Overall	38
Source: National Bank of Kuwait	

Oilfields /source	Estimated Production Costs ($ 2008)
Mideast/N.Africa oilfields	6 - 28
Other conventional oilfields	6 - 39
CO2 enhanced oil recovery	30 - 80
Deep/ultra-deep-water oilfields	32 - 65
Enhanced oil recovery	32 - 82
Arctic oilfields	32 - 100
Heavy oil/bitumen	32 - 68
Oil shales	52 - 113
Gas to liquids	38 - 113
Coal to liquids	60 - 113

(http://www.reuters.com/article/idUSLS12407420090728)

According to the International Energy Agency World Energy Outlook's study done by analysts in 2008 regarding oil production costs by country, operating and capital costs of oil range from $6 a barrel to about $40 a barrel, which are significantly higher compared to operating and capital costs of natural gas.

Barriers to Expanding the Use of Natural Gas – Summary

Gas Transit

- Many utilities do not provide necessary means for transporting gas from wellhead to gathering system. Also, owners of gathering systems (the interconnecting utility) often do not have the necessary incentives to maintain or expand systems

Infrastructure Finance

- Potential investors to finance new gas infrastructure should be encouraged – this will improve flows and remove bottlenecks
- Currently, disincentives include utility claims that the operation of a proprietary pipeline is a violation and a "sham" that deprives the utility of rents, and include fines
- Unclear rules prevent investors from freely finance infrastructure projects

Regulatory Clarity

- Oil and coal lobbies have thus been much more powerful and influential, being able to fund more lobbying efforts since coal and oil especially is a more profitable resources (with extremely high royalty costs and profit-making opportunities), thus creating a regulatory disadvantage for the natural gas industry, expansion of infrastructure, and investments in projects to expand use
- It should be mandated that utility owners of gas-gathering facilities expand and maintain them to maximize gas production, and it should be made clear that these facilities are different from those that cater to retail customers
- The use of these facilities will help to maximize the flow of domestic gas to the marketplace
- If a utility is unable to receive gas into its system, regulation should allow the producer to bring gas directly to storage facilities or other pipelines to speed up the transport process and allow stranded gas into the marketplace

- Clear rules should be communicated to allow potential natural gas infrastructure investors to fund projects without legal restrictions, challenges, or fees

(http://www.powermag.com/issues/departments/legal_and_regulatory/Barriers-continue-to-crimp-natural-gas-supplies_262_p3.html)

Additional Barriers:

- Greater investment opportunities elsewhere
- Higher gas prices may make prospects more attractive
- Carbon markets may also enhance attractiveness
- United States Public Utility Commissions do not currently provide incentive for reducing emission of methane
- Lack of extensive technical knowledge of the market and existing opportunities
- Governments in some cases through monopoly gas companies create a barrier to access this market

  http://www.ipieca.org/activities/climate_change/downloads/workshops/26sept_06/Session_3/Robinson.pdf

Appendix: Technology

New technology in Natural Gas

Distributed Power Generation

Microturbines

-operates at hundreds of thousands of revolutions per min at operating pressure of 60 psig
-Currently we are aiming to produce 30kW-300 kW
-installation cost: **USD1000**
-mass production cost: **400-600USD**
-electrical efficiency: 30%
-compact, light, and quiet without need for liquid cooling
-low nitrogen oxide combustion
-low maintenance→ attractive for on-site power generation for certain residential and commercial applications
-cost of power production→ between **1/3-1/7 of local electricity prices**!
Companies producing these: *Allied Signal Power Systems, Rolls Royce-Allison Mobile Power Systems…etc*

Fuel Cells

Phosphoric Acid Fuel Cells

-**3000USD** per kilowatt
-electrical efficiency: 35%
*However, up to 80% thermal efficiency is possible if co-generation steam can be produced from the waste heat generated from the 200C⁰ operation
-cost of PAFC must be reduced to about **1000-1500USD** per kW to compete with **0.05-0.06 prt kW** hour electricity
-at present, total of about 170200kW PAFC units are used commercially in hospitals, nursing homes, office buildings, hotels, banks and a variety of power plants

Molten Carbonate Fuel Cells (MCFC)

-operate at 600C^{o} and generally targeted for modular systems of 250kW capacity
-power production efficiency: 50%
* However advanced integrated MCFC co-generation systems could approach 70%
-installed cost needs to be reduced to **1500-2000USD** to compete with electricity prices
Major developers: *Energy Research Corporation, IHI Ishikawajima-Harima Heavy Industries Company Ltd. Hitachi*

Solid Carbonate Fuel Cells

This generates power electrochemically using natural gas, clean coal derived fuel gas, coal bed or coal mine methane, and landfill or waste water digestion gases. Unlike the molten one, the solid oxide concept uses zirconia ceramics, which must be operated at higher temperatures (1000C^{o})
-a unit generates 200kW electricity
-power production efficiency: 55%
*However, with cogeneration it could reach 80%
-SOFC can easily follow changing demands for electricity
-the solid state composition of SOFC allows many of the robotic mass production techniques that have reduced costs in the electronics industry to be applied to the power sector
-Disadvantage: needs costly super alloys and exotic ceramics, gas leakage cracking and problems associated with high temperatures
-Installation cost **below 700USD**

Polymer Electrolyte Membrane Fuel Cells (PEMFC)

With this technology, natural gas is reformed with steam and/or by partial oxidation in a fuel processor and the resulting synthesis gas is further processed to produce a hydrogen-rich gas which is fed as fuel to the PEMFC
-operates at the lowest temperature (60-80C^{o})
-Efficiency: 20%
-Advantages: suitable for both stationary and propulsion applications
-PEMFC stacks with 3-5kW can target residential applications, while modular systems with 100s kW can target multi-floor apartment complexes and less than 100kW for small commercial business
Development: *Daimler-Chrsler, Siemens, NuPower, Mosaic Energy*
-Cost of production potentially be reduced to **200USD per** kW (it needs to be **below 0.05 per kW hour** to be competitive)

Innovative Natural Gas Usage

These examples are supposed to demonstrate how flexible natural gas can be!
-Harley-Davidson Motor Company uses natural gas fired regenerative thermal oxidizer to destroy the organic compounds released from painting operations
-The California Medical Center generates electricity for most of the facility from two 800kWe engines. Waste heat from gas engines used to supply hot water, operate absorption chillers and sterilize medical supplies and equipment. But co-generation system isolates system from grid. Surplus power was put on the grid to generate revenue for the medical center

-Brach and Brock (fourth largest candy maker in Chicago) installed a Kathapac 1600 FV desiccant dehumidifier to deliver air at 15-35% humidity to pans of candy in order to ensure interrupted production of candies

Other developments…

Developments at IGT (Institute of Gas Technology)

-forced internal recirculation (FIR)

-METHANE de-NOX

-Oxygen-enriched air staged natural gas combustion→this will help gas industry meet stringent air quality regulations

-MORPHYSORB (new way of 'refining' gas to pipeline quality)→ reduced capital cost by 20%, operating cost 20%-60%

Appendix: Deregulation

<u>Natural Gas Contracting in North America</u>

Before Mandatory Open Access	After Restructuring
At Wellhead	
Producers contracted to sell gas to pipelines	Producers contract to sell gas to: -End users -LDCs -Marketers, including pipeline affiliates who sell to end users and LDCs
Prices regulated by FERC	No price controls
Pipeline companies aggregated supply for customers	Customers aggregate supplies on contract with producers or marketers for this service
Pipelines responsible for supply reliability	Customers responsible for supply reliability
Downstream	
Gas customers obtained gas from pipeline companies through bundled sales and transportation service	Customers contract separately for gas from any seller and transportation from pipeline companies. Customers can buy a bundled service from marketers.
Transportation typically along one path, often involving a single pipeline company. Interconnections used mainly for emergencies.	Customers determine the least-cost combination of transportation route and source of gas supply

Operational adjustments to maintain system integrity handled entirely by pipeline companies	Customers are liable for penalties if they do not meet scheduled volumes and match receipts and deliveries within tolerances. Services available to avoid or reduce penalties
Pipelines companies controlled most storage for seasonal load balancing and operation control	Customers are responsible for reserving adequate storage to meet peak day requirements
Pipeline companies offered interruptible service when capacity not fully utilized	Firm shippers can release excess pipeline capacity and recoup oar tot all of reservations costs