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Survey of Energy Resources: Focus on Shale Gas

World Energy Council 2010

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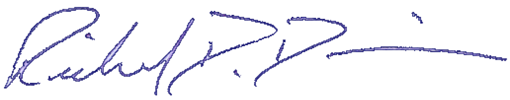
Foreword

The energy sector around the world is undergoing major changes resulting from increasing competitive pressures and concerns about costs, security of supply and the environment. At the same time, 1.6 billion people, almost a quarter of the world population, do not have access to commercial energy and the need for energy infrastructure investment is huge. The energy challenges are not the same in all regions. While rapidly burgeoning economies in the developing world are focusing on expanding energy access to support their economic growth and provide basic energy services to their citizens, industrialised countries are focusing on securing energy supplies in a competitive environment and in a publicly and environmentally acceptable way. In recent years, shale gas has been making headlines as a potential solution for many of the energy-related challenges, in particular in the United States. A number of studies on shale gas have been conducted, the majority focusing on the assessment of the resource base and the role of emerging technologies, which can significantly increase the current reserve estimates.

The World Energy Council has just completed work on its 22nd Survey of Energy Resources and based on this work, it was decided to produce a “Focus on Shale Gas” report to provide a fact-based and forward-looking contribution to the on-going discussion about shale gas. An ad-hoc team of experts led by Richard Davis of RTI International included Vikram Rao of RTEC (former Chief Technology Officer of Halliburton) and Carl Bauer of C.O. Bauer Consulting (former Director of the U.S. National Energy Technology Lab). The Survey of Energy Resources joint-editors Judy Trinnaman and Alan Clark, and RTI International experts James Trainham and David Myers contributed their insights. The project was managed by Elena Nekhaev, WEC Director of Programmes.

WEC Survey of Energy Resources

The starting point for any discussion about energy is the availability and type of primary energy resources, technologies for their exploration, production and utilization, associated costs and other aspects, including public acceptance and the environment. For over 70 years, WEC has been producing a triennial Survey of Energy Resources based on the research conducted using its membership network, regional energy organisations and various other expert bodies. The Survey is the most comprehensive collection of data and other relevant information about global energy resources conventional, unconventional and renewable resources. Electronic copies of the Survey are available for downloading from the WEC website at www.worldenergy.org free of charge.



Rich Davis, RTI International, USA

Executive Summary

Today, the global energy industry is facing a growing number of uncertainties, including price volatility, rising demand and increasing costs which are leading to greater pressures for energy producers and consumers alike. Furthermore, almost a quarter of the world population has no access to modern energy and little hope of joining the world's energy consumers any time soon. It is clear that the current energy system is unsustainable. Can shale gas induce badly needed changes?

In its quest for secure, sustainable and affordable supplies of energy, the world is turning its attention to "new" and promising energy resources. Shale gas is one of them, and it has been making headlines in the past couple of years. It seems to be abundant and globally available. Massive recoverable deposits of shale gas have been identified in North America, where the first commercial gas well was drilled nearly two hundred years ago, in 1821.

Emerging Shale Gas Plays

According to geologists, there are more than 688 shales[1] worldwide in 142 basins. At present, only a few dozen of these shales have known production potentials, most of those are in North America. This means that there are literally hundreds of shale formations worldwide that could produce natural gas. The potential volumes of shale gas are thought to be enormous and this is likely to change the natural gas markets significantly, particularly in the United States and Europe, and also LNG (Liquefied Natural Gas) markets worldwide.

Developing shale gas infrastructure will be costly, but today in 32 of the 142 basins there is some existing infrastructure that could reduce initial capital expenditures related to exploitation of shale gas. However, even in these basins there is likely to be significant need for capital investment to process, store and distribute the gas through a pipeline system. In the remaining 110 basins with no existing infrastructure, the required investment will be considerable and this may result in delaying new production coming online or make the entire exploitation uneconomic, although for strategic or other reasons, shale formations may be still worth exploiting. Of course, each shale formation will be evaluated on its own merit.

Shale Gas Resource Base and Current Developments

While it is believed that the shale gas resource base is both large and wide-spread, the resource has not yet been quantified on a national level for most countries. The most credible studies (IGU 2003, VNIIGAS 2007, USGS 2008, BGR 2009) put the global shale gas resource endowment at about 16,110tcf or 456tcm compared to 187tcm for conventional gas. It is assumed that nearly 40% of this endowment would be economically recoverable. The US and the CIS together account for over 60% of the total estimate. European resource estimates, on the other

[1] **Shale** is one of the major types of sedimentary rocks.

hand, are not very impressive at slightly over 7% of the estimated global resources, and China and India on current estimates hardly reach a 2% share each.

It should be emphasised that these are best estimates available today and they can change significantly when more proper assessments are performed. The US provides an enlightening example. In 2007, US shale gas resource base (see Definitions at the end) was estimated at 21.7 tcf, but only a year later it was revised up to 32.8 tcf. At the end of 2008, shale gas accounted for 13.4% of US proved reserves of natural gas, compared with 9.1% at the end of 2007.

Approximately one half of these new proven reserves are shale deposits, the rest are contained in coal seams and sandstone. Even if the current attention on shale turns out to be no more than a temporary boon, further development of natural gas infrastructure will be useful for other sources of natural gas. Moreover, the advancement of technology used to exploit shale gas will spur further technical advancements for other energy resources. An additional major challenge to developing shale plays will be the need for new or expanded pipeline infrastructure near these shales.

Oil majors and other global companies are expanding their shale gas activities outside the United States. For example, ExxonMobil and Marathon Oil have launched shale gas operations in Poland. France, Germany, Sweden, Austria and other European countries are also establishing shale gas activities.

Strategic Implications

The emergence of shale gas as a potentially major energy resource can have serious strategic implications for geopolitics and the energy industry. Although global resource estimates are still mostly theoretical, analysis leads to the following conclusions (see Strategic Implications Section for more detail):

1. Based on the current reserve estimates in Europe, Russia and Southeast Asia, Russia stands to be the European and Southeast Asia winner in shale gas. The on-going rapid depletion of Europe's own scarce natural gas resources coupled with the economic growth in China and India will result in additional demand for Russian gas. Consequently Russian gas, including shale gas will likely be used in Europe and Southeast Asia for decades.

2. European shale gas resources are likely to be less than desired by many countries. Although shale gas exploitation can benefit some European countries, it will not significantly reduce dependency on gas imports from Russia and the Middle East.

3. The proved reserves of shale gas in North America and the existing LNG infrastructure create the potential of LNG exports to Europe, which can help Europe to diversify its natural gas supply sources. This is likely to provide marginal quantities of natural gas and

not materially replace demand for Middle Eastern or Russian gas.

4. Shale gas resources in the United States will keep natural gas prices relatively low for an extended period of time. Longer periods of lower gas prices will likely result in additional demand for gas from the transportation and power generation sectors.

5. LNG will face short to medium-term headwinds as a result of increasing natural gas supplies which cause price declines. Over the long-term, LNG is likely to be the winner as a result of the improved infrastructure built to exploit shale gas. In areas where shale gas resources are depleted, the infrastructure will remain and will thus provide broader downstream distribution opportunities for LNG.

6. The environmental impact of hydro-fracturing processes used in shale gas exploitation will likely draw political and public attention to shale gas and increase the costs of extraction.

7. The use of shale gas will have a significant impact on CO_2 emissions and on the imperative to implement clean coal technologies and Carbon Capture Storage. The more shale gas available, the less need for clean coal and CCS and vice-versa.

Demand Shifting

As shale gas production ramps, regional natural gas prices are likely to decline and the gas use to expand. As long as power generators assume that gas prices will be lower than coal on a BTU basis (potentially also including carbon mitigation costs), they will shift toward using more natural gas power generation.

Low gas prices and increased supplies over the long-term could provide an incentive to the industry to introduce wholesale shifts in oil replacement. This can occur at two levels. The first will be the direct use of CNG (Compressed Natural Gas) for transportation, likely mostly for public transport. Diesel replacement in the commercial sector in environmentally sensitive areas will likely take place. The second could be by increased use of GTL (Gas-to-Liquids), especially from gas stranded without pipelines to demand areas. An example of this would be Alaska North Slope gas. A future with a low price of gas would incentivise research in improving GTL economics. Were this to be successful, GTL derived fuel could become a significant force in the transport fuel market, since it is extremely clean, and the net impact on the environment would go well beyond mere oil replacement.

Conclusion

It can take decades to realise all the consequences of the increased production and use of shale gas on natural gas markets, in particular. There are a number of uncertainties which can have a significant impact on the future of shale gas. Given the fact that there are still significant producing reserves of conventional natural gas around the world, there may not be sufficient incentive, on a regional basis, to identify or exploit unconventional natural gas in the near term. It may also be the case that the amount of energy needed to produce unconventional gas is considerably higher than for conventional gas. Developing nations will also face the challenge of the cost and time to develop both the resource and infrastructure as economic returns will be initially small.

It is impossible to put a numeric value on security of supply, but replacing oil imports from politically sensitive parts of the world by domestic shale gas production is perhaps the main driver in the United States.

The advantages of expanding the use of shale gas include:

- Adding significant quantities of natural gas to the global resource base;
- Shorter time to first production compared to conventional gas;
- Using cleaner energy resource;
- Broader use of new drilling technologies around the world; and
- Improved security of supply for gas-importing countries.

On the other hand, the most often mentioned drawbacks are:

- Uncertainty over costs and affordability;
- Doubts about the environmental acceptability of the production technology;
- Unclear rates of decline which may materially impact reserve estimates; and
- Local opposition to shale gas development.

It would seem that although shale gas holds much promise, the eventual course of its development cannot be predicted at present. Helge Lund, Chief Executive of Statoil, was quoted by the Financial Times in FT.com in March 2010 as saying ‘it is far too early to conclude whether shale gas will make as much of an impact outside the US as it has done inside the US’.

1. Emergence of Shale Gas

1.1 Definitions

Shale gas belongs to the category of unconventional natural gases, which also includes coal-bed methane, gas from tight sandstones ('tight gas') and methane hydrates. Shale is a sedimentary rock formation which contains clay, quartz and other minerals. Much of the oil or gas formed in the shale (this body is known as source rock, being the source of the hydrocarbon) migrates to porous and permeable rock, such as sandstone, for example.

(For further definitions refer to end of the report).

Where shale gas is found

It could be assumed that shale gas is always found proximal to conventional reservoirs. In fact source rock exists in many settings where no conventional reservoir rock is available for permeation of natural gas. This is why the shale gas resource is expected to be plentiful. Virtually all the US deposits are in very old rock. In comparison, gas in the Gulf of Mexico is found in younger rock. The age and depth of the shale gas deposits assures that the fluid is in gaseous form and essentially no associated oil is found. Similar source rock can be found in other parts of the world, even in those without significant conventional gas reservoirs. The depth of shale gas varies. In most cases it is shallower than conventional gas reservoirs, but in some cases, it could be as deep or deeper than conventional reservoirs.

1.2 Background

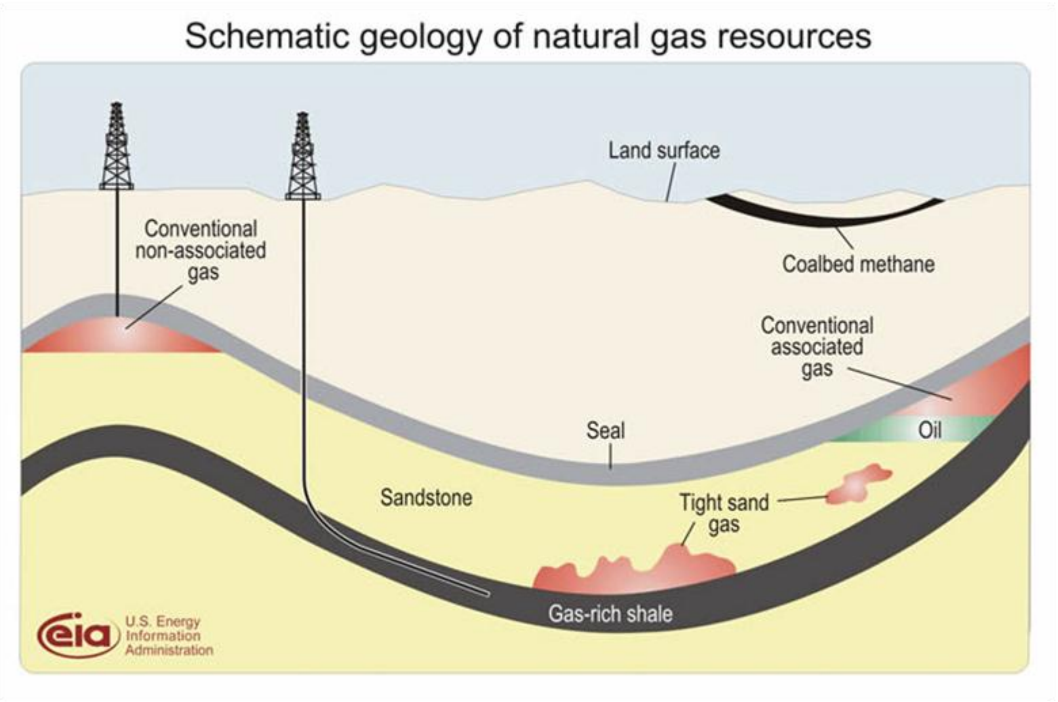
The first commercial gas well in the USA, drilled in New York State in 1821, many years before Drake's pioneer oil well, was in fact a shale gas well. Subsequently, limited amounts of gas were produced from shallow, fractured shale formations (notably in the Appalachian and Michigan basins). Until quite recently, however, total US shale gas production was negligible, being completely overshadowed by vastly greater volumes of natural gas produced from conventional sandstone and siltstone reservoirs.

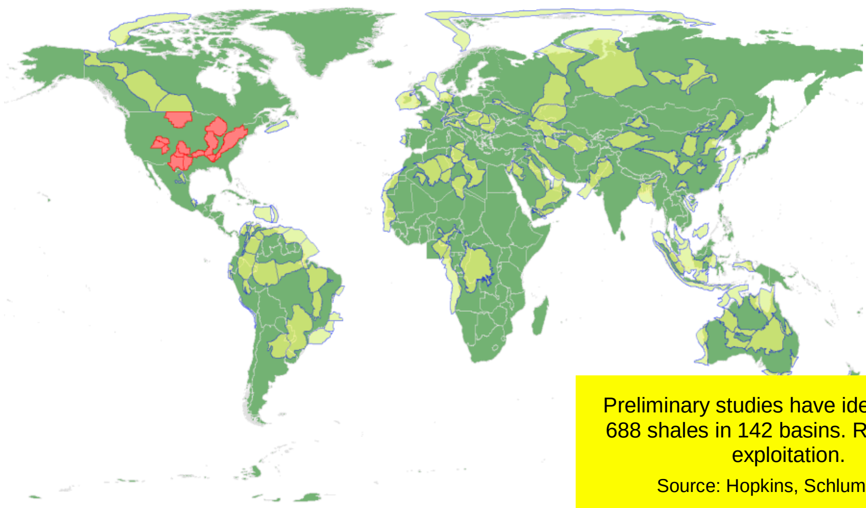
Although the existence of shale deposits across the world has been well-known for many years, most shales have not been regarded as potential sources of commercial quantities of natural gas as they have insufficient natural permeability to permit significant fluid flow to a well bore. The relatively few instances of commercial shale gas extraction in the past relied on the existence of natural fractures in the formations. The transformation in thinking about the shale gas potential that has occurred in recent years is not attributable to the discovery of new resources or the re-assessment of old resource estimates but to the development and application of new technologies that in effect 'create a permeable reservoir' and achieve high rates of production. This is why many consider this to be a resource exploitation play rather than an exploration play.

1.3 Resource Base

Shale gas resources, although believed to be widespread, have not as yet been quantified on a national basis for most countries, apart from the United States and a few other countries. Recent studies estimate the resource endowment (gas in-place) of five major shale gas basins in the USA at 3,760 tcf, of which 475 tcf is considered to be economically recoverable, while two Canadian basins are estimated to hold 1,380 tcf, with about 240 tcf recoverable.

Until recently the shale gas focus was mainly on North America, but today the interest towards shale gas is spreading to other countries, too.





Preliminary studies have identified over 688 shales in 142 basins. Red = active exploitation.

Source: Hopkins, Schlumberger

For example, the ARI (Advanced Resources International) status report specifies three European basins as of particular importance – the Alum Shale in Sweden, the Silurian Shales in Poland and Austria's Mikulov Shale. Together, these basins are estimated to have a shale gas resource of around 1,000tcf (roughly 30tcm), of which about 140tcf (4 tcm) is considered to be recoverable.

The share of shale gas in US natural gas production rose from 1.6% in 1996 to nearly 10% in 2008. There was a sharp jump in US shale gas reserves estimates in 2008, from 21.7tcf at end -2007 to 32.8tcf a year later. At end-2008, shale gas accounted for 13.4% of US proved reserves of natural gas, compared with 9.1% at end-2007. In particular, the unexpected economic success of the Barnett Shale project in Texas has generated a rush for other sources of shale gas across the US and Canada.

Outside North America, shale gas has not yet been produced commercially because of a limited geological knowledge about shale gas and host reservoirs as well as the higher technical and economic costs.

Exploration has commenced in Poland, the country which today totally depends upon Russia for its gas supplies, and where domestic production of shale gas could change the regional politics.

Similarly, India has very little domestic gas production, and almost all of it is based on young rock offshore. A costly pipeline from Iran is being considered for supplies of natural gas to India which currently pays market rates for LNG, typically several times more than the controlled price for domestic production. This price was under US$3 per mBTU (US¢10/cm) until it was recently raised to US$4.20. (US¢15/cm) This is still considerably lower than for the supply of LNG from Iran or Qatar, which is estimated to reach US$13 (US¢46/cm) at the point of delivery.

Notwithstanding the lack of accurate data, it seems obvious that shale gas can contribute significantly to the supplies of natural gas world-wide.

It is unknown how many of the identified shales around the world are thermally mature, gas prone or potentially productive. Of the 688 shale formations, only a few dozen have been explored for production capacities. Consequently, resource and reserve estimates can be susceptible to substantial change as exploration progresses to new shale formations. Further, geological evidence suggests that shale gas may, in fact, be almost ubiquitous.

It is expected that as hydraulic fracturing technology spreads, more accurate reserve data will become available.

A considerable amount of exploration activity is being undertaken with the objective of establishing the location of viable shale gas reservoirs, mostly by relatively small companies, although there are signs of increasing interest on the part of some of the international majors. Examples of such activity have been reported for the following countries: Austria; Australia; Canada; China; France; Germany; Hungary; India; New Zealand; Poland; South Africa; Sweden; United Kingdom; and the United States. Brief details of the exploration companies and geological basins involved in these countries are provided in the Country Notes section of Chapter 5: Natural Gas in the WEC Survey of Energy Resources, 2010 edition.

The volume of shale gas worldwide could become a strategic factor for future energy use and this is only now beginning to be understood. Global and regional markets for LNG, power generation, heating and transport fuels could all be exposed to major changes in the coming years as a result of this new ample resource.

1.4 Technologies

The transformation in shale gas production has been achieved largely by a combination of horizontal drilling with hydraulic fracturing. In this procedure, a well is sunk to a depth somewhat less than that of a known shale gas deposit and then gradually deviated until the drill-bit is running horizontally through the shale bed. Once drilling has been terminated, the rock surrounding the horizontal bore is perforated in a number of locations and artificial fracturing induced by the high-pressure injection of water combined with special additives and sand - called a proppant - to keep the fracture open.

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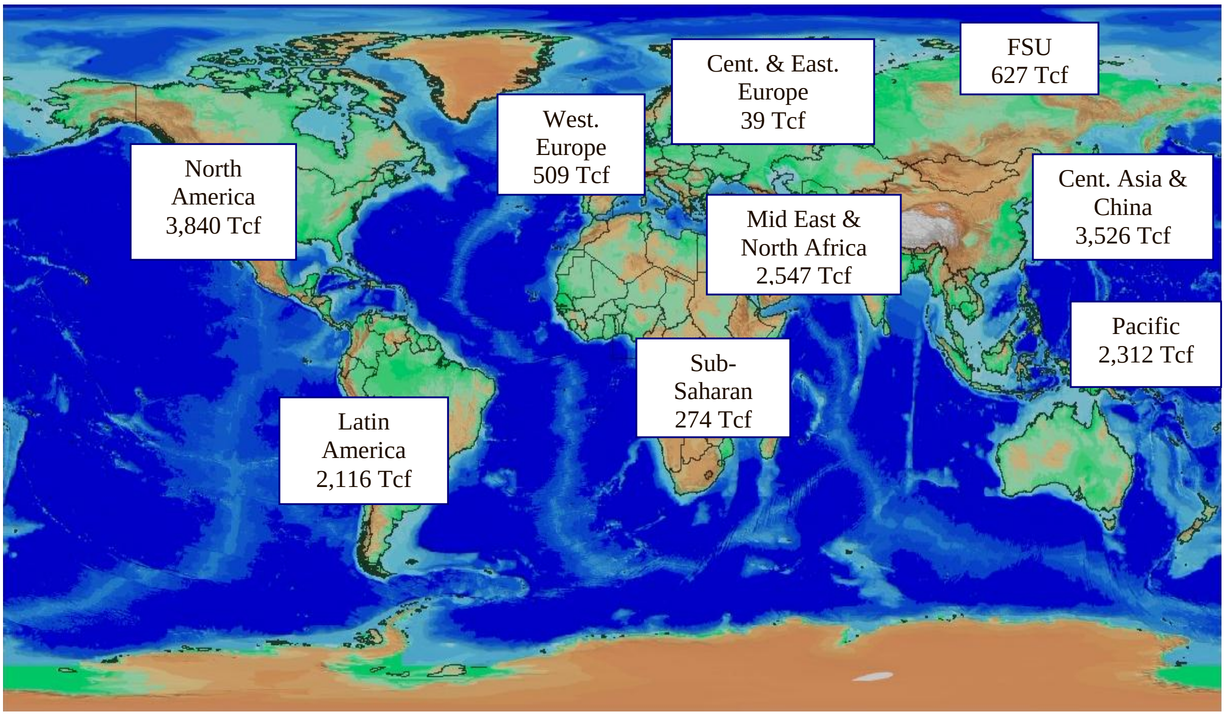
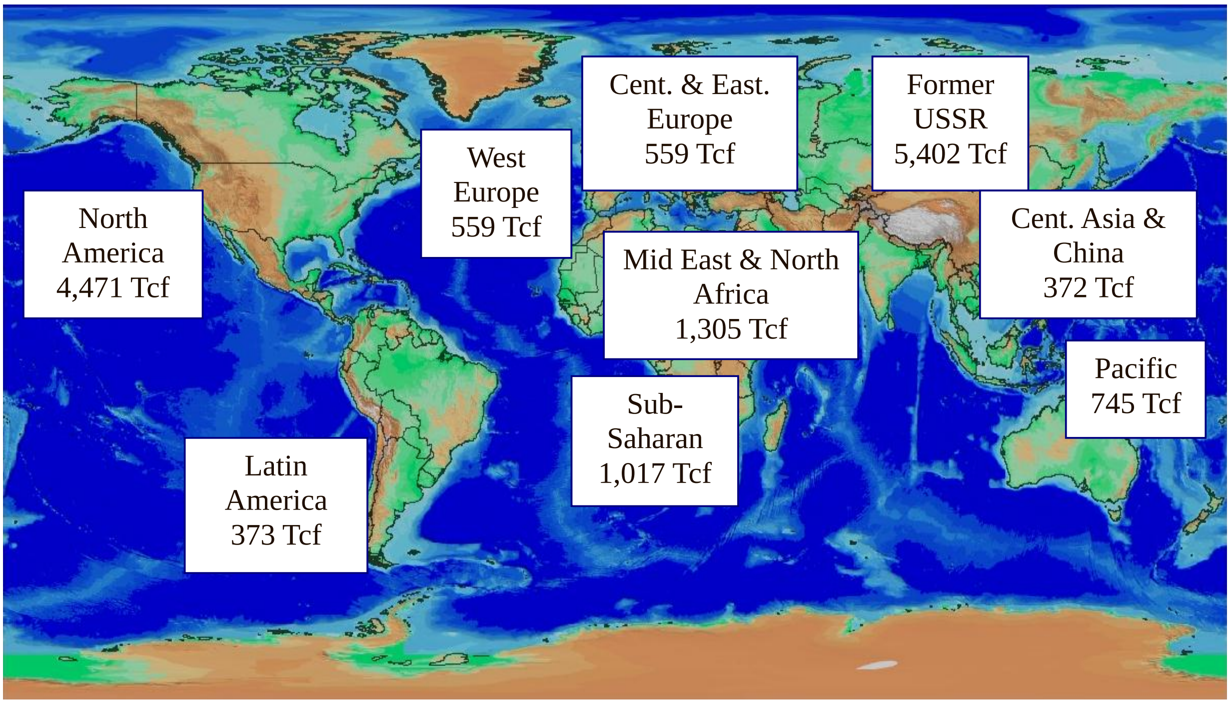
Estimated Shale Gas Resource Potential - 2001



Kawata, et al, 2001

Estimated Shale Gas Resource Potential - 2010



IGU 2003, VNIIGAS 2007, USGS 2008, BGR 2009

The Rock

Technology starts with exploration and in many cases this process is much easier technically compared to the search for conventional hydrocarbons. The geologic risk of not finding the deposits is low. However, finding sufficiently large occurrences with recoverable quantities is the key. The vital metric of interest is the Total Organic Carbon (TOC). Commercial deposits in the US run from about 4-10%. A higher number is indicative of more gas.

The gas in the shale is in two principal forms. One is free gas, much as it is in conventional reservoirs. The other is adsorbed gas, wherein the gas is on the surface of organic matter (again higher TOC is good). It is released when the pressure drops through production of the free gas.

This manner of gas storage is similar to that in coal bed methane. The most productive shale is high in TOC and is relatively brittle. Some natural fractures can be beneficial. The low permeability means that the only way to produce the gas is by fracturing the rock further. Hence the need for brittleness. That is a property driven by the non-organic mineral composition, primarily comprising oxides of silicon, aluminium and calcium. Its future prospects are determined by taking core samples to establish organic content and assess mechanical properties of the rock.

Fracturing

Fracturing of the rock is accomplished by injecting water with some chemicals into the well under high pressure. In conventional wells, the water contains a gel (commonly a derivative of the guar gum seed and essentially the same material used to thicken ice cream and other liquids) which increases viscosity. The viscous liquid is pumped in at high pressure. This fractures the rock. The liquid is then “broken” with small amounts of a metallic based compound called a "cross-linker" to reduce the viscosity, and it flows back out of the rock. Before this is done, sand or some other such material known as proppant is injected into the fractures. These “prop” the fractures open to allow gas to flow. Were this not to be done, the natural stresses in the rock would “heal” the fractures shut and gas flow would cease. This healing mechanism is also the reason why fractures distant from the zone of interest are unlikely to propagate towards the surface. Changes in the rock above the shales also hinder upward growth of fractures.

The conventional fracturing techniques used to be seen as damaging the production by leaving gel residue. A breakthrough was the adoption of Slickwater Fracturing (no gels in the fluid). Most shale gas operations now run “slick”. However, some gel may be used on occasion. The substantial absence of gel allows entry into micro-cracks and enlarges them. The drawback is that much more water is needed. This can be up to 5 million gallons per well. But the significant plus is that very few total chemicals (sugars, bromates, polymers and typically chlorine-based biocides) are used, less than half of one per cent by weight.

Other Technologies

The other major advance that made shale gas so promising was horizontal drilling. The technique per se is not new and is practiced all over the world. The dramatic increase in production rates over vertical wells justified the higher cost of these wells. The majority of them are lined with a steel casing embedded in cement. Whether cased or not, most of the wells have what are known as multi-staged completions. This is a technique involving isolation of the productive zones and fracturing just those zones. Ten or more of these zones are not uncommon. Another technique employed is directing the well at an angle to the maximum horizontal stress to allow transverse fractures, which maximize production. All of this involves fairly sophisticated geophysical mapping of the rock.

An important new technique well suited to shale gas exploitation is pad drilling. This is where multiple wells are drilled and completed from a single location. This minimizes the need for roads and reduces the overall footprint of operations, especially important in populated areas, or farmland and other environmentally sensitive areas. It also allows for a higher level of sophistication in material handling. As discussed later, this could be important for water treatment.

Are These Technologies Available Worldwide?

In principle they should be available anywhere, since they are used by the major service companies operating worldwide. The horizontal drilling expertise is probably the easiest to make available. But the high capital cost of fracturing equipment and materials and its sheer bulk could well limit availability in some parts of the world. Furthermore, the biggest operators are US-based and the rapid expansion of domestic activity will make this business segment more attractive and eventually provide an incentive to expand abroad.

One factor that could affect all this is that foreign energy companies are increasingly taking equity positions in the US shale gas play. The Europeans have been doing it for some time, Statoil of Norway, for example and more recently the Chinese and Indians have entered the fray. The Chinese focus on Canada's British Columbia (where the shale gas may be even more promising than in the US). The Indian giant Reliance Industries has agreements to take two positions in the US. Almost all the foreign companies buying into North American shale gas business are doing it with intent to acquire and transfer technology. However, it is not that simple and in the end the technically demanding work will have to be performed by specialised service companies, and they will need incentives, not the least of which will be assurance of long-term work.

1.5 Production Costs of Shale Gas

There is significant debate over the production costs of shale gas. Estimates of shale gas extraction costs in North America range from US$4- 8/Mcf. The differences in estimates is significant and complex. On the one hand, low-price proponents argue that exploitation of shale gas can be as little as three months from the beginning of the drilling effort. Further, they say the ease of hydro-fracturing multiple times is reason that the price will remain low for the foreseeable future. High-price proponents argue that the actual drilling costs are more significant and will be pushed higher as environmental regulations are established. Costs related to water reclamation and chemical cleanup will add to production costs which could drive prices between US$6-8/Mcf.

Recent regulations established by the U.S. Environmental Protection Agency require drillers to adhere to more environmentally friendly practices. This will certainly drive production costs higher. In time, there will be a better understanding of the exploration price in each shale basin. The problem today is that the costs are not well known because it is too early to understand the implications of decline rates and environmental regulation. That said, as new regulations are established, the margin between shale gas and traditional basin exploitation costs will likely narrow over time.

Globally, the price of shale gas extraction will be determined by accessibility, environmental regulation and proximity to natural gas infrastructure. In shale basins that are isolated, of course, the costs will be higher due to the need for processing stations and pipelines to markets.

1.6 Shale Performance

Decline Rates

This is roughly defined as the rate at which production declines after an initial burst known as Initial Production (IP). The figure of interest for reserve estimates is the Estimated Ultimate Production (EUP). The popular literature among engineers and investors has been replete with discussion of these parameters. Much has been made of the fact that decline rates in shale gas well have been significantly greater than for conventional reservoirs.

Why might that not be a worry? For one, we are only just beginning to understand this type of reservoir. Initial fracturing was done with gels and impaired the production. When these were repaired using slickwater, the production was dramatically enhanced. Currently most wells use slickwater. But their ability to carry proppant is poor because proppant is much denser than water and tends to settle. Many of the smaller fractures and those further away from the well bore likely have no proppant. Initially these will produce and later the earth stresses will close due to overburden and other stresses and production will be reduced or stop from this source. This is one possible explanation for the high decline rate.

Taking this one example, technology will likely ameliorate this problem. Low specific gravity proppant is one solution. A more fruitful avenue would be to radically re-think the problem and assure flow through some completely different mechanism for keeping the cracks open. The general conclusion is that these are early days and mechanisms continue to be better understood, and therefore ingenious solutions for improving productivity are very likely and should be pursued by the industry.

Re-fracturing

An example of technology already overcoming early declines is re-fracturing. This is where new fractures are initiated in existing well bores that have already been hydro-fractured, often at the same location as the previous perforations of the old ones. New rock is believed to be exposed by this step. This is a technique used in conventional reservoirs as well, but in the few cases that it has been tried in the Barnett shale, the results have improved dramatically, much more than in conventional wells. The fast declines in output are then not so important, if this requirement is met. How will it impact reserves and hence the size of the national resource? If it really is economical to keep punching more holes or keep re-fracturing old ones, then the play is viable. This is all feasible only because the deposits are on land and relatively easy to access. Ultimately, improved hydro-fracturing technology will probably render the re-fracturing unnecessary. As to reserves estimates, here is a truism in the industry - reserves continue to increase as the new resource is increasingly exploited. Expect this to be the case for shale gas as well.

1.7 Environmental Issues

The issues facing shale gas are largely those common to all petroleum production activities. They are getting magnified in the Marcellus exploitation regions because of the novelty of such activity in the states of New York and Pennsylvania. The latter was the location of the first oil well in the US. The placement of wells in farming areas raises special challenges, even if the farmers get a new source of substantial revenue.

The industry has faced similar challenges in Colorado and some of the recent innovations will apply. One of the more important ones is pad drilling. This technique allows the drilling of multiple wells from a single location. This has the virtue of aggregating operational equipment. Given the technical sophistication of these operations, there are benefits to the operator as well. It provides, for example, relatively expensive capabilities such as broad band satellite and associated decision centers. This allows to the use of remote monitoring and decision support, thus minimizing risks. It should also allow for aspects of regulatory oversight without major personnel additions because a single inspector could monitor up to a dozen or more sites. This point addresses a concern most prevalent in Pennsylvania today, that staff needs of regulatory personnel are inadequate relative to the expected burgeoning activity.

A collateral benefit of pad drilling is the minimization of building and use of access roads. This could be particularly important in farming areas and near centers of higher population density. The nature of fracturing operations is such that heavy equipment is needed at each well head. Pad drilling allows this to be shared. This will be particularly important for newer methods for water treatment that will benefit from economies of scale.

Chemicals in Fracturing Operations

The chemicals present in fracturing fluids can include:

- Gels to induce viscosity. These are derivatives of a natural seed, guar gum. Most shale gas operations run “slick”, meaning without any gels. However, some gel may be used on occasion.
- Cross-linking agent - used to make the gels viscous (boron or zirconium based organo-metal).
- Breakers, to break down the cross links, if gel is used (often enzymes).
- Lubricants (mostly polymers).
- Biocides (at present bromine based, have been chlorine based).

The vast majority of operations use slick water, so the first three components in the list above do not come into play. Until recently there has not been open disclosure of the nature and amount of each chemical employed. This has unnecessarily raised the level of anxiety. Complete disclosure of the nature and properties of the chemicals should not prove onerous. Further, environmental studies will provide additional understanding of the impact of existing technical processes. For drillers, resorting to more benign chemical substitutes is possible, and companies will vie to be greener as environmental impacts and regulations become more well known.

In total the concentration of chemicals in fracturing water is less than half per cent and often less than a tenth of one percent. Consequently, combined with an effort to eliminate toxic chemicals and the likely move towards recycling of fracturing water, chemicals in the fracture fluid will become less of an issue. However, industry will need to do its part by being transparent and proactive in securing public support. NGO’s (non-governmental organizations) and other stakeholders should be included in this activity to support impartiality.

Fresh Water Withdrawals and Flow Back Water

Slick water practice causes water usage to go up. Typical wells use between 3 and 5 million gallons per well. Industry practice has been to use fresh water as the base. The water that is brought back up after the fracturing step is known as flow back water. Shale operations are unique in that only about a quarter to a third of the water returns, the rest staying in the formation. Also, the flow-back water is usually brackish. This is because the water in the pores is usually very salty, as discussed in the Geology section. So, in principle it cannot be re-used.

Handling this salinity is the first big objective of water conservation. The key is ability of the water to tolerate some level of chlorides. Recent research has shown that not only is this possible, but that it can be beneficial. The chlorides actually stabilize the clay constituents of the shale and improve production, although companion chemicals such as friction reducers need to be modified. This has two possible implications to water withdrawals.

One is that after some measure of treatment, the flow back water should be usable. But because all of it does not return, withdrawals for makeup water will be necessary. This is where the second implication comes in. It should be possible to get moderately saline water from another source since salinity is tolerable in the operation. The most important implication of the foregoing is that flow-back water could, and over time should, be completely re-used and cease to be an issue relative to discharge. Of course, proper attention to temporary retention will be required, at it would be for any fluids handling in a rig operation.

Today, the drilling industry can likely tolerate 40,000 ppm chlorides in its hydro-fracturing process. If the flow-back water comes in with higher chloride content, it will need to be desalinated to some degree, or diluted by fresh water withdrawals. In some part of the country this latter operation is likely completely tractable. Another option could well be to use sea water, if that was the water of convenience. Sea water tends to run around 30,000 ppm chlorides, plus or minus 5000, or so. That is already in the range of acceptability with the possible removal of some minor constituents. Finally there would be the option of producing from saline aquifers. These are in great abundance, although with highly variable salinities. Saline water wells drilled as companion to the gas wells are very likely in areas with challenging surface water availability.

Eventually one could expect the industry to develop fracture fluids tolerant of even higher salinities. That would open up some very interesting outcomes. Today sea water and brackish water reverse osmosis plants have a problem waste comprising brines with about 75,000 ppm dissolved solids. This waste could potentially be usable by the drilling industry, pending environmental study. The shale gas industry could move from being a net drain on the fresh water environment to becoming an example for water sustainability.

Produced Water

Water associated with the gas is produced at some stage of the recovery, usually at the tail end of the process - this is water trapped in the pores of rock (connate water) in or near the shale formation. In some cases early production occurs due to infiltration of the fractures into the underlying saline water body. The Ellenberger and the Onondaga are water-bearing formations below the Barnett and Marcellus reservoirs, respectively. The Onondaga in particular is very high in salinity and this unwanted fluid will be produced if the fracture direction is not controlled. By contrast, some shale gas reservoirs are very dry (meaning that they don't have connate water in or near the shale formations), as for example portions of the Haynesville (Louisiana).

Whether from connate water or the water layers below, the water will be very saline, in part because of the age of the rock. Disposal of this water is a major issue, especially in New York and Pennsylvania and can cost upwards of US$10 per barrel or $500,000 per well, when even possible. Concern regarding illegal discharge is high among the residents.

The treatment of produced water represents a significant business opportunity. Several companies are developing forward and reverse osmosis schemes for desalination. Others are working on bacteria eradication, heavy metal removal and the like, using methods such as membrane filtration and ion exchange. Some of these are already in service on a limited basis.

Produced water offers the promise of being usable for makeup water after some modest treatment. The salinity may be directly tolerable but any bacteria would need to be removed prior to re-use. This is because many of these cause the production of hydrogen sulphide down hole, which makes the gas less valuable and causes corrosion in the equipment. Other reported contaminants in produced or flow back water are heavy metals which sometimes contain trace amounts of radioactive material. The latter are usually extremely low in concentration but often precipitate out as a scale with other salts. In that form they are more concentrated. All of these metals can be removed by ion exchange, oxidation and other methods.

Contamination of Drinking Water

There have been anecdotal reports of well water contamination by gas or the hydro-fracturing fluid, most recently sensationalized by a documentary, Gasland. The popular literature ascribes two hypotheses to this phenomenon. One is the migration of fracturing operation cracks from the reservoir up to the water body. The other is gas or fluid leakage from the well.

Aside from the fact that cracks will not propagate the significant distances to the aquifers, were they inclined to do so, they would likely heal due to the earth overburden stresses. In terms of distance, the closest fresh water aquifers are vertically about 5000 ft. and 3000 ft. away, respectively, for the Barnett and the Marcellus.

Gas leakage from the well should not happen if the well is drilled and completed correctly. A fundamental feature of regulation has always been to design for isolation of fresh water in all petroleum exploitation, not just in the shale.

Between the produced fluids and the aquifer lie two layers of steel encased in cement. The first layer is the so called Surface Casing and the second is the Production Casing. There may be more layers, but this is a minimum. The cementing operation is designed for preventing fluid migration. Tests are run to ensure competence of the cement job and remedies are available for shortcomings. At these shallow depths the operation is extremely straightforward and amenable to regulatory oversight.

In summary, the environmental issues related to shale gas production can be addressed in a similar way as for other fuels, i.e. by a combination of technology, regulation, and transparency. The importance of shale gas to national priorities such as energy security, a low carbon future and health of industry calls for all concerned collaborate to expeditiously understand and then deal with the issues.

1.8 Renewable Standards and Carbon Regulation

Climate change concerns leading to regulation on CO_2 production and greenhouse gas (GHG) management are under development and discussion at both national and international levels. The concern about climate change has increased the interest in renewable energy sources and to some degree nuclear power for electricity generation as the means to limit future increases in GHG emissions.

The US federal government has not yet implemented a national renewable portfolio standard but is having substantive discussion and such a standard may well be expected in the next several years. Left to pure market dynamics, renewable technologies have not fared well against traditional fossil fuels and hydro-based electricity generation or transportation fuels. The sources of energy that are recognized as renewable include biomass, solar thermal, solar photovoltaic, wind, geothermal, small and large hydroelectric schemes, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, and tidal.

Advanced clean technologies for fossil fuels, including carbon capture and sequestration, can achieve significant CO_2 reductions but presently they are not considered as commercially deployable. That said, natural gas has half the carbon as coal and therefore half the carbon output. Should regulation limit carbon output, natural gas will certainly be a winner.

The energy demand of the world is huge and growing fast, as emerging nations become increasingly prosperous. The challenge of meeting the scale and rapid growth in energy demand from renewable energy is daunting both from the magnitude of the need and the economics of addressing it with renewable sources. Shale gas can play an important role of balancing a system with a high share of intermittent renewable sources.

In addressing the GHG challenge and scale of energy demand a major increase in supply and use of natural gas as an alternative to coal may provide a bridge to the future that makes the changes required over the next several decades more palatable if that gas can be made economically available. Over the past several years there has been no new coal facility built in the United States. This underscores investor concern over pending regulatory action by states or the federal government related to carbon emissions. On the flip side, gas-fired power plants are in development and the additional resource of shale gas not only makes the plants more economically viable but also hedges against potentially punitive carbon regulation.

However there are increasing concerns of the environmental challenges to be addressed in pursuing this source. There is also the reality that methane (natural gas' major constituent) is a GHG with a much more significant near term (within 20 year time frame) heating impact on the atmosphere than CO_2.

Renewable energy sources are also facing increased environmental scrutiny as their locations may sometimes interfere with endangered species or utilize significant quantities of water relative to the actual power they produce.

Geothermal energy production has been known to bring up and release CO_2 or even hydrogen sulfide. Solar areas have concerned biodiversity - the desert tortoise and sage grouse - as well as use surprisingly significant quantities of scarce water for thermal solar plants. Newer plant designs include air cooling with corresponding higher investment and new heliostat designs that do not require clearing of desert terrain. It would seem there are no absolute simple best answers but the opportunity through balanced consideration of the various issues to move forward addressing demand, environment and economics wisely can lead to better solutions.

2. Impact of Shale Gas

2.1 Exploration and Production

To understand exploration and production issues of shale gas, it is necessary to understand the specific issues faced in the mature shale gas plays in North America and the emerging shale gas plays elsewhere.

North America

Massive exploration and exploitation of shale gas has begun in earnest in North America over the past few years. The result of the exploitation activity has resulted in the region becoming a net exporter of gas, instead of importer. Energy utilization actions now range from shifting electricity production from coal to the potential of shale gas driving change in transportation fuels market. Time, investment decisions and public policy will likely influence the outcome of the impending decisions.

Exploitation of traditional gas basins over the past several decades resulted in the development of infrastructure like pipelines, storage systems, processing stations and a distribution network for commercial utilization. This infrastructure is currently utilized for a good part of the shale gas production. However, significant shale reserves lie outside the existing pipeline grid and require capital investment to build the infrastructure necessary to utilize the gas. According to the Interstate Natural Gas Association of America, it is expected that US$133-210 billion will need to be invested during the next 20 years to process the gas coming from shale and other tight gas formations. The lesson is that extracting shale gas is only one cost, processing and distributing it downstream add other costs, but clearly have not deterred investment into these more remote fields.

Prudent management of capital or the lack of it is also an issue in North America. Although spot prices for natural gas have other factors involved than just supply & demand fundamentals, the spot price of natural gas has fallen from over US$13 (US¢46) in 2008 to under US$5 (US¢17) per mBTU in mid-2010. Although the global economic slowdown was part of the price decline, the ramping up of shale gas extraction has also flooded the natural gas market during the same period.

In a rush to exploit shale gas, producers have caused a glut in natural gas supplies resulting in record highs of natural gas supplies in storage. Given that some traditional gas basins have productions costs of US$4-5 per mBTU (US¢14-18/cm), the aggressive pursuit of shale gas is causing production losses at traditional gas fields.

Consequently, this pace of natural gas production is not sustainable and evidences the lack of capital discipline and over-drilling at present. Over time, equilibrium will be found between supply and demand, which means supply will lessen or demand will increase

Exxon Mobil's acquisition of XTO is an example of how valued shale gas production is to the future of oil majors. Total, British Petroleum, Exxon Mobil, Conoco Phillips, Shell, Chevron, Repsol and other oil majors have begun to invest in shale gas production.

This indicates a strategic shift in portfolio for the major oil companies. Given the capital requirements of extraction, processing, storage and distribution, it is likely that oil majors will play a significant role in the exploration and extraction of new shale gas plays inside and outside North America. The consequence of oil majors in shale gas plays is unclear at present other than a general expectation of more stringent operational procedures relative to environmental protection.

2.2 Demand Drivers & Fuel Switching

Since natural gas is central to many industrial goods and processes, its availability and price can have a profound effect on the economy. A few years ago the sustained high price of natural gas had a considerable downstream effect on many industries, particularly the chemical industry. Natural gas pricing is largely regional, because the gas transport over distances has a high cost. Over the water, it can only be transported as liquefied natural gas (LNG), which typically adds about US$3-4 to the price (mBTU), depending on the distance. Consequently, if a given region has sustained high natural gas prices, certain industries will not be viable and could be forced to relocate.

Over time, gasification of biomass or even coal - if it can be kept clean - will provide a source for some of these chemicals. However, today natural gas has no economic alternative. A reliable domestic production and supply of gas at low to moderate prices can offer the required certainty to industry.

For natural gas to replace coal as a producer of electricity in any material way, there must be an assurance of supply and a reasonable price in the short to medium term. Gas replacing oil can be through the electric car route or direct combustion in vehicles, compressors and the like.

Gas Replacing Oil

Compressed natural gas (CNG) is often used in fleet vehicles and public vehicles. Most buses, taxis and rickshaws in New Delhi and Kuala Lumpur are powered with CNG and the beneficial effect on the air quality has been remarkable. This is because the fuel replaced is diesel, which has high particulate emissions.

The Pickens Plan utilizes abundant natural gas resources in the United States to reduce US reliance on foreign oil and to improve security of supply for transportation fuels. The Pickens Plan calls for widespread adoption of the switch with gasoline as well. In cars, the downside is the gas container taking up trunk space. On the plus side natural gas is cheap. The cost per unit of energy is about one third that of oil in the US today. Supply infrastructure for CNG is also an issue, especially for trucks.

Electric cars offer another solution for road transport. Aside from the zero tail pipe emissions, the allure is the high efficiency. The so-called well (or coal mine) to wheel efficiency of gasoline powered vehicles is around 16%. Using the same assumptions, that number is close to 28% for electric cars when the electricity is produced from a natural gas-fired power plant. That is a huge improvement in fuel used to drive the same number of miles. The fuel cost will be a fraction of the price of gasoline provided low cost night charging is done. From a natural gas consumption standpoint this is an indirect route through electricity generation.

Gas Replacing Coal

Many coal-fired generators are being retired for cost and/or environmental reasons. Their replacement with natural gas-fired plants is lower cost even when compared to regular coal fired plants. Operating costs are therefore the dominant contributor to the unit cost of electricity generated. As a rule of thumb, gas at US$4 per mBTU (US¢14/cm) will deliver electricity at about 4.5 cents per kWh. Coal will on average deliver at about 6 cents per kWh but can also be cheaper with fully depreciated equipment. If coal emissions are reduced to the natural gas levels, that should add about 3.5 cents to the cost of electricity.

Security of Supply

About three years ago this issue would have had a different answer. The discussion would be about liquefied natural gas (LNG) imports and environmental risks posed by that. Shale gas has changed all of that. The US can expect to be self-sufficient in gas for a hundred years. In fact, it may become a net exporter of LNG. As an alternative, the US could reopen the possibility of LNG export of Alaskan North Slope gas. Due to the net shortages in the US, this had been politically impossible except for a single permit for LNG export from the Cook Inlet. Now, that may no longer be an issue and in fact ConocoPhillips has sought an extension to the Cook Inlet permit. Shale gas from the Horn River basin in British Columbia is already slated for LNG export by Apache. Gas export from North America could become a marketing force in the coming years.

2.3 Traditional Sources of Natural Gas

Unconventional Natural Gas has gained much recognition recently with the breakthroughs in technology allowing more economic access and large-scale production of the shale gas plays. It would almost be easy to forget that the world still gets the majority of it natural gas from traditional basin reserves of which 46% are located in the Middle-East & North Africa (MENA) region. While the traditional basins are to some degree diminishing in their productivity, there are still very large and significant quantities of gas to be realized but at incrementally increasing marginal costs.

The traditional large basin holders had contemplated the formation of something akin to OPEC (e.g. Russia, Iran, Qatar, etc.). But with the rapid pursuit of shale gas resources such an international organization is unlikely to organize, at least for now. Although, shale gas resources are likely to impact traditional gas producing nations, the impact may not be negative. For example, Russia, has significant traditional reserves along with significant quantities of shale gas resources. New downstream infrastructure built to exploit shale gas will benefit tradition basin owners as well.

LNG from traditional basin resources will continue to provide liquidity of movement to those traditional customers. Where significant quantities of shale gas can access infrastructure to LNG preparation and shipping terminals there may an economic impact on the LNG markets not presently evident.

Another aspect of traditional gas sources in North America (especially the US) is that often traditional gas deposit opportunities have been placed off limits by environmental policy decisions. The development of ever more environmentally benign access technologies that are economically viable may in the future bring more traditional gas resources back into play.

2.4 Pipeline Infrastructure

World gas resources are plentiful but the regions with natural gas surpluses are often literally oceans away from the greatest demand. While the technologies exist commercially to meet the challenge of developing resources and delivering natural gas to markets where its use is growing often the cost and time required to authorize and construct the infrastructure leads to decades of delay in the realization of benefit by all parties.

The re-discovery of shale gas has broadened the potential opportunity for some countries previously not anticipating significant domestic natural gas resources. Many of these countries have immature or non-existent gas infrastructure.

The West European continent and the North American continent have fairly mature and well developed gas pipeline and storage infrastructure systems. Yet even these relatively mature systems will be challenged by a substantial increase of natural gas supply and use. This was indicated in the recently released 2010 Congressional Report Services (CRS). This report, on the use of natural gas to displace the use of coal in the US for electricity generation recognized that while the quantity of natural gas could address and displace up to (35%) of coal-based power production.

Coal proponents argue that when real-world constraints are factored into the analysis (e.g., transmission systems, dispatch, supply and price, transportation, and storage), natural gas could replace only 5%-9% of coal-fired power generation (i.e., no more than 4.5% of total electricity generation).

The dynamics of gas infrastructure operation are significant and require much more than pipelines. The existence of infrastructure if already in full use will not permit the expansion of more gas into the system without additional infrastructure. Another aspect increasing the complexity of moving gas from its source to the end user is the fact that in many areas of the world, pipelines need to cross borders between countries which may create additional or new geopolitical challenges for the development of infrastructure and operations.

An often undervalued but essential part of the infrastructure is storage. Not all geological areas are amenable to providing storage. The operation of the pipeline and the consistent provision of supply at pressure as demands may swing with weather and other influences are best and most cost effectively addressed by adequate storage. China is developing the second extremely long East-West natural gas pipeline from Turkmenistan to serve Eastern China's high population centers. Further, they are adding substantial storage capacity along the pipeline inside China. India is also significantly increasing it pipeline infrastructure and storage capabilities to benefit from the addition of both LNG terminals and expanded gas field development.

2.5 Gas Prices in the Future

Major movements in capital do not easily occur in an uncertain pricing environment. Clean coal-based electricity can be expected to cost in the vicinity of 9 cents per kWh. This assumes that coal-based power will need to reduce emissions to levels present in natural gas-fired power (like the mandates in California). It also assumes that technology will be available for bolting on to existing plants and that it will be applied to the newer plants carrying depreciation.

For natural gas to be cost-competitive, it will need to be priced something under US$8.50 per mBTU (US¢30/cm). Today the pricing hovers close to US$4 per mBTU (US¢14/cm) What can one expect in the future?

Commodity pricing is extremely hard to predict. After all, this is a fuel which spiked to US$13 per mBTU (US¢46/cm) not that long ago. However, a close examination of the data shows that over a decade the price was above US$12 per mBTU (US¢42/cm) for only about four non-contiguous months. The true comfort regarding price moderation comes from the setting in which shale gas is found.

In the United States, most shale gas is either proximal to the intended market, as in the case of the Marcellus, or close to major pipelines, as in the case of the Barnett, Haynesville, and Woodford, to name just three big ones.

- Compared to conventional gas, these wells are relatively shallow and on land. When prices go up, new gas production can commence in 90 to 180 days. This short time span will basically keep a lid on natural gas prices. Speculators will be aware of the quick response ability. This throttle effect will likely keep prices under US$8, possibly even lower.

- At numbers over US$4 per mBTU (US¢14/cm) most operators will make a very good profit. An indication is the price being paid for shale gas assets today. So the businesses will be sustainable and continuous supply assured. Note: LNG has a built in cost of US$3-$4 just to transport it, over and above the production cost.

In summary, a major shift from coal to natural gas is a sensible and likely course of action. In the US, one can expect supply to remain robust and pricing to remain moderate to low. For the world, shale gas resources are likely to have regional impacts in proportion to the volume of shale gas reserves.

The substitution of oil is a priority in many countries, at a different level: reducing the reliance on imported oil. Here too, assurance of reliable domestic supply of natural gas and a low natural gas price can only help.

3. Strategic implications

The emergence of shale gas has strategic implications on geopolitics and the energy industry. European dependency upon Russian Gas has seen stormy times and created tensions between exporter, transfer and importer nations. Dependency on foreign oil has plagued domestic politics in countries like the United States and China for years.

Global companies have invested billions in establishing an international market for LNG which now seems threatened by the vast and dispersed resource of shale gas. Coal switching to natural gas has traditionally been an economic decision, but now in many countries, decision making is shifting to economic & environmental considerations. Although global resource estimates are still theoretical, the following analysis provides insight as to the likely manifestations of shale gas impact in the years to come.

European Dependency upon Russian Gas

When the Ukraine had gas turned off by Russia due to political tension between Kyiv and Moscow, the act was seen as a direct threat to all gas importing nations in Europe. Leaders across Europe are hopeful that shale gas quantities in Europe will help alleviate the reliance on Russian gas. European industries willingly participate in exploration and extraction of resources but this has only just begun in Poland and the Ukraine.

Current resource data, presented earlier in the paper, indicates that European shale gas is limited and not as large as expected in previous estimates. That said, only a few of the more than 20 shale formations in Europe have had shale gas exploration. Therefore, Europe is likely to see increases to the shale gas resource and reserve estimates in the coming years. Although European shale gas may add gas reserves, it is unlikely to offset the continuing decline in existing reserves and the increased demand for natural gas due to the phase out of European power generation facilities over the next two decades. Additional European demand impetus will come from the aging power generation infrastructure, where nearly 30% of base load capacity will need to be replaced within the next two decades. It is unlikely that nuclear or CCS will be able to close the emerging gap.

Although Europe is likely to benefit from US exports of LNG, rising demand in Europe will not be satisfied by these new resources. As such, Russia will continue to supply European countries with natural gas, including shale gas for decades.

Transportation Fuel - Dependency on Oil

China and the United States are dependent upon foreign oil to feed their economies, particularly their transportation systems. In both countries, dependency on foreign oil has led to political challenges. In the United States, presidents must address the energy security threat posed by dependence on foreign oil. With oil at US$80 a barrel, the United States sends over US$500 billion to oil producing countries every year. Natural gas proponents are getting louder and gaining more political traction as the emergence of domestic shale gas supplies is seen as a potential transitional fuel that can be used to develop transportation fuels (CNG and GTL).

Metropolitan bus systems and taxis are already shifting to compressed natural gas. This trend will continue as energy security proponents argue that the low price of natural gas can help rid dependency upon foreign sources of oil. Shale gas reserve statistics do support the claim that natural gas could be used in the transport fuel sector for many years. Chinese shale gas resources are not as thoroughly known or understood as the United States resources. In China there are over 20 shale formations that need to be explored for shale gas potential.

As exploration commences in the coming years, it is likely that China will use a majority of the resource for power generation, the rest may go toward transport fuels. Given China's growing energy demand, it is unlikely that domestic supplies of shale gas would remove the need for energy imports from Central Asia and the rest of the world. The likely outcome is that China will continue to burn coal to help meet rising demand for electricity.

Liquefied Natural Gas

LNG terminals have been established across the world at enormous expense to industry. The emergence of shale gas impacts the future of LNG in three ways: First, LNG importing countries like the United States are likely to stop importing LNG and may even become exporters of LNG. But, obtaining permits for export of LNG from the USA may prove extremely difficult. Second, the distribution and exploitation of shale gas may suppress LNG demand for a few years. Third, the vast supplies of shale gas are likely to promote further shifting of demand to natural gas, which in turn will strengthen the global LNG market, particularly due to the build-out of natural gas pipelines which will aid LNG over the long-term. In the mid to longer term, gas dependency could be as "addictive" as the present oil "addiction".

Liquefaction and transport carries a cost of approximately US$3.00 to US$4.09 per mBTU. As a result, LNG costs face headwinds competing in markets that have increasing supply of low cost shale gas coming on-line. LNG import terminals in the United States are now being designed to export LNG.[2] This development is likely to be good for the LNG industry because it further develops distribution channels. That said, the vast supplies of shale gas coming online suppress the needs for North American imports of LNG. This will be the case for years to come.

The addition of shale gas supplies is likely to put downward price pressure on natural gas. Expected low natural gas prices will shift demand away from higher priced energy to the lower priced gas. This downward price pressure will be met with additional demand. It

[2] http://phx.corporate-ir.net/phoenix.zhtml?c=101667&p=irol-newsArticle&ID=1434471&highlight=

is this additional demand that will likely improve the condition of LNG markets, but there will be a lag effect to the exploitation of natural gas.

Power Generation - Coal Switching to Gas

As shale gas production ramps, natural gas prices decline. As long as power generators have visibility which indicates gas prices will be lower than coal on a BTU basis (potentially including carbon mitigation costs), power generators will shift toward natural gas power generation.

Low gas prices over the long term will make it very difficult to implement high-capital-cost clean coal technologies, particularly given the public perception of coal production and use versus natural gas. It will also impact the economic justification of CCS and likely delay its implementation for years, depending upon the cost of carbon emissions.

Britain Case - Strategic Decision Disappointment

In the 80s and 90s, Great Britain built out a natural gas infrastructure based upon projected vast supplies of natural gas from the North Sea. Billions of British Pounds were invested into the infrastructure development. As time passed, and decline rates increased, it became clear that Britain had invested in a resource that was not unlimited.

As such, there has been domestic political fallout from the heavy investment into the North Sea infrastructure, which left Britain reliant on expensive LNG imports.

Decision makers and investors will likely use the British case to scrutinize the investing decisions surrounding shale gas, particularly in countries where existing infrastructure is minimal or non-existent.

Relationship between Gas and Oil

For a few years now there has been a disconnect between oil and gas prices. Curiously, the more environmentally challenged resource, oil, is currently priced at roughly three times gas price. That is commodity pricing in action.

The disparity is even greater when refining costs are taken into consideration. The price differential is a result of the value of the internal combustion engine being the workhorse of transportation and economies.

In developing economies, the largest of which had substantial net GDP growth even in 2009, prosperity equates to the transition from bicycles to scooters to cars. Fuel for mobility will therefore be the single greatest factor in demand improvement of natural gas in an environment where oil gets harder to extract and higher in price.

'…..it is far too early to conclude whether shale gas will make as much of an impact outside the US as it has done inside the US….'

Helge Lund, CEO, Statoil

Abundant and inexpensive natural gas will also be a boost to industrial productivity as a whole because it is the backbone of so many industrial goods. The collateral benefit of gas being potentially available more widely than today is security of supply. Currently oil and gas imports cause net importing nations to pay not only market but also political and military prices, in addition to other externalities. Abundant supplies of shale gas could help correct this price imbalance.

Definitions

Natural Gas Resource Definitions (Source: EIA):

- ***'Unconventional'*** natural gas does not exist in these conventional reservoirs - rather, this natural gas takes another form, or is present in a peculiar formation that makes its extraction quite different from conventional resources.

- ***The Natural Gas Resource Base*** - The broadest classification of natural gas estimates is generally termed the natural gas resource base. According to the U.S. Energy Information Administration the total natural gas resource base includes the entire volume of natural gas contained and trapped in the earth, before any is extracted and produced.

- ***Economically Recoverable Resources*** - Economically recoverable resources are those natural gas resources for which there are economic incentives for production; that is, the cost of extracting those resources is low enough to allow natural gas companies to generate an adequate financial return given current market conditions. However, it is important to note that economically unrecoverable resources may, at some time in the future, become recoverable, as soon as the technology to produce them becomes less expensive, or the characteristics of the natural gas market are such that companies can ensure a fair return on their investment by extracting this gas.

- ***Reserves*** - Those discovered, technically and economically recoverable resources are further broken down into different types of 'reserves'. Organizations measure reserves for their own use and for outside publication, often using different measuring and estimation techniques for the different types of reserves. However, in general, reserves can be broken down into two main categories - proved reserves, and other reserves.

- ***Proved Reserves*** - Proved reserves are those reserves that geological and engineering data indicate with reasonable certainty to be recoverable today, or in the future, with current technology and under current economic conditions.

Produced Water - Water associated with the gas is produced at some stage of the recovery, usually at the tail end of the process - this is water trapped in the pores of rock (connate water) in or near the shale formation.

Flow-Back Water - The water that is brought back up after the fracturing step is known as flow back water.

4. References

1. Groppe's Argument for the Doubling of Gas Prices - http://seekingalpha.com/article/207668-groppe-s-argument-for-the-doubling-of-gas-prices-part-ii?source=from_friend

2. Cohen, Dave. "A shale Gas Boom?". 25 June 2009. Post Carbon Institute: Energy Bulletin. http://www.energybulletin.net/node/49342.

3. Congressional Research Service. "Unconventional Gas Shales: Development, Technology, and Policy Issues". 30 October 2009. R40894. http://www.fas.org/sgp/crs/misc/R40894.pdf.

4. Dizard, John. "The shale gas fairytale continues". 18 July 2010. Financial Times. http://www.ft.com/cms/s/0/9e6c7b40-9103-11df-b297-00144feab49a.html?referrer_id=yahoofinance&ft_ref=yahoo1&segid=03058.

5. Hopkins, Chris. "Unconventional Gas - Beyond North America". Presented at CERA Week 2010. Schlumberger Oilfield Services.

6. Moniz, Ernest et al. "The Future of Natural Gas: An Interdisciplinary MIT Study". Interim Report. June 2010. Massachusetts Institute of Technology. http://web.mit.edu/mitei/research/studies/naturalgas.html.

7. National Energy Technology Lab. "Modern Shale Gas - Development in the United States: A Primer". April 2009. www.netl.doe.gov.

8. Pickens, Boone. "Pickens Plan". 15 August 2010. http://www.pickensplan.com/.

9. Vaughn, Ann and David Pursell. "Frac Attack: Risks, Hype, and Financial Reality of Hydraulic Fracturing in the Shale Plays". 8 July 2010. Tudor Pickering Holt and Reservoir Research Partners.

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