Natural Resources Research, Vol. 12, No. 4, December 2003 (© 2003)

North American Natural Gas: Data Show Supply Problems

Walter Youngquist[1,3] and Richard C. Duncan[2]

Received 25 July 2003; accepted 15 August 2003

Natural gas is increasingly the fuel of choice for domestic and industrial use and for electric power generation. With pipelines in all 50 states, gas now fuels more than one-half of United States homes. Demand for all uses is projected to rise. United States production peaked in 1971, and is in decline. The United States in 2002 imported 15% of its gas from Canada, which amount was 56% of Canada's production. However, Canada's production now also is in decline. Mexico's production declined from 1999 to 2002 against rising demand. Mexico is increasingly a net gas importer from the United States. In both the United States and Canada, intensive drilling is being offset by high depletion rates. Frontiers for more production include deep basin drilling, improved exploration and reservoir development technology, increased coalbed methane exploitation, and access to lands not now accessible because of environmental and other restrictions. Stranded gas in Arctic regions of the United States and Canada offer some potential for additional supplies, but pipeline access is at least five years to ten years or more away. Additional LNG landing facilities are needed, and are planned, but these are several years away in significant numbers. For the immediate future, rationing of available gas by the market mechanism of higher prices seems the only option. In the longer term, it seems North America will be increasingly dependent on LNG.

KEY WORDS: Coalbed methane; deep gas; LNG; natural gas; population; stranded gas.

INTRODUCTION

Natural gas supplies for North America seem to be of more critical concern than oil supplies for at least the next decade. One portent of this was a spike in the natural gas contract price on the New York Mercantile Exchange for March 2003, to a record high of $11.89 per thousand cubic feet (mcf). This compares with an average price of $1.60 mcf from 1996 to 1999, and $2.45 mcf average the past three years. Gas now seems to have reached a new plateau of $4 mcf or higher for at least the immediate future. The financial community is becoming concerned about natural gas supplies as reflected in a recent report issued by the research department of a firm oriented toward natural resource investments stating: "... we remain more convinced than ever that the U.S. is facing a supply driven chronic gas shortage scenario for the next several years! With our expectation of dwindling gas supplies (regardless of drilling activity), the only solution is a market induced 'rationing' of available natural gas through higher gas prices" (Adkins, 2003).

Once considered a nuisance to be disposed of, natural gas has become a premium fuel in rapidly growing worldwide demand. Two of many articles forecasting the rising importance of natural gas are: *Natural Gas Central to World's Future Energy Mix* (Carson, 1997), and *The Future Looks to be Gas-Fired* (Durham, 2003). Although improving technologies of natural gas transported as liquefied natural gas (LNG) are reducing costs, and more LNG ships, loading, and regasifying facilities are being built, natural gas supplies will remain for some time to come mainly a continent by continent supply situation.

[1] Consulting Geologist, P. O. Box 5501, Eugene, Oregon 97405.
[2] Institute on Energy and Man, 1621 California Ave. SW #2, Seattle, Washington, 98116; e-mail: duncanrichardc@msn.com.
[3] To whom correspondence should be addressed; e-mail: wyoungst@mindspring.com.

1520-7439/03/1200-0229/1

THIS REPORT

The purpose of this report is to present a summary of the current North American natural gas situation, and the outlook for obtaining supplies to meet the projected demand for the next two to three decades. The present supply position is described. Prospects for future supplies in terms of where and in what time frame they might be obtained are examined. Economic and environmental circumstances related to natural gas supplies are also considered.

DRILLING EMPHASIS NOW ON GAS

In contrast to earlier times, about 80% of wells now drilled in North America are for gas, not oil. This emphasis is likely to continue. In the United States in the first quarter of 2003 there were 967 drill rigs operating of which 782 (81%) targeted gas. Lending further impetus to exploration efforts are the high depletion rates new gas discoveries are experiencing (Simmons, 2002).

Total North American gas production in 2002 was 27.0 trillion cubic feet (tcf). Of that, the U.S. produced 71.5%, Canada 24.1%, and Mexico 4.4%. North American cumulative production at year-end 2002 totaled 1,164 tcf, of which the U.S. accounted for 84%, Canada 13%, and Mexico 3%. Clearly, the United States has been, and is, the dominant producer in North America. North American gas production history is shown on Figure 1.

NATURAL GAS DEMAND

The United States is both North America's and the world's largest consumer of natural gas, using 23.6 tcf in 2002. This compares with Canada 2.8 tcf, Mexico 1.5 tcf, European Union 13.6 tcf, and entire world 89.5 tcf (British Petroleum Statistical Review of World Energy, 2003). The United States thus used 26% of the world total. Gas pipelines now reach all 50 states. Gas heats more than one-half the homes (about 56 million), and nearly 70% of new housing developments are designed for natural gas heating. Gas has become the fuel of choice for electric power generation. In the United States between 1999 and 2002, 144,000 megawatts (MW) of electric generation were added of which 138,000 MW used natural gas and only 1000 MW used coal. More than 90% of generating capacity now

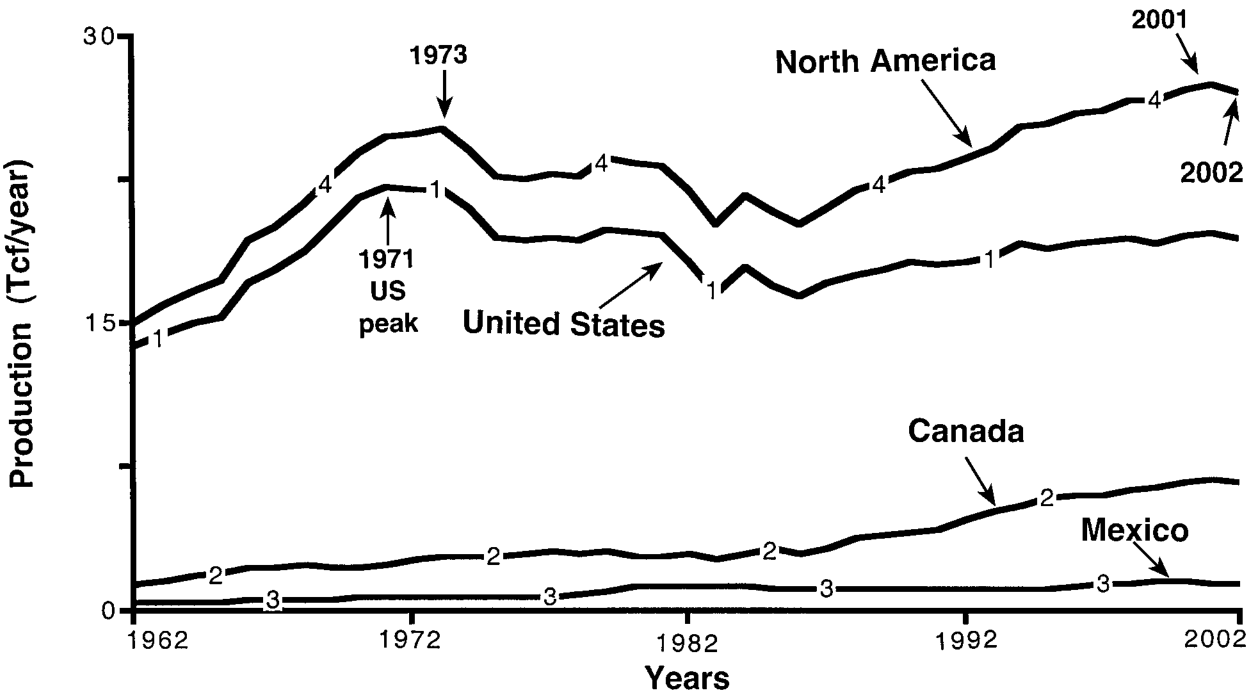

Figure 1. Natural gas production: United States, Canada, Mexico, and North America.

being built is gas-fired. The Energy Information Administration (EIA) of the U. S. Department of Energy projects that demand for natural gas used for electric power generation will increase from 7 tcf in 2001, to 8.7 tcf in 2015 and to 9.4 tcf in 2020, an increase of 34% (EIA, 2003).

Cleanliness of natural gas burning with the simplicity of transport by pipeline, absence of on-site problems of fuel handling and storage compared with coal, and absence of flue particulate discharges or other ash disposal problems, make natural gas superior to coal. Combined-cycle power plants now operate at up to 55% efficiency compared with 34–41% for coal-fired plants. Siting requirements of gas-fired plants (especially environmental concerns) as well as their cost and time of construction are less than for coal-fired plants of equal power output.

At 50% efficiency, a combined-cycle unit uses 6,630 cubic feet of gas to produce one megawatt hour of electricity at the plant. This quantity is reduced ultimately by transmission line loss and the approximately one percent of electricity used by the plant operation. Total of both may approach 10%.

Approximately 36,000 MW of new gas generation went on line in North America March through September 2003. Of that, about 94% is located in the United States, 4% in Canada, and 2% in Mexico. These additions include a mix of combined-cycle units for 79% of the total MW, and combustion turbine units for 21% (NERC, 2003). With an assumed average efficiency of 54% and an average run-time of 21 hours a day for the combined-cycle units, and 38% efficiency and 14 hours a day for the combustion turbine units, these additions add 1.7 tcf to the present annual demand for gas in North America.

The EIA has projected total demand for natural gas in the United States to increase 48% by 2020, which would mean an annual consumption of 34.8 tcf compared with 23.6 tcf in 2003. This EIA projected growth rate, if achieved, would be the largest ever by historical standards. Simmons, primarily extrapolating the growth rate of use of gas for electric power generation, projects United States demand to reach 40 tcf in 2015 (Simmons, 2000). Can either projected demand be met? No predictions are being made for reduced demand.

NATURAL GAS PRODUCTION AND POPULATION

The relationship of gas production to United States, Canadian, and Mexican populations is shown in Figure 2 (IDB, 2003).

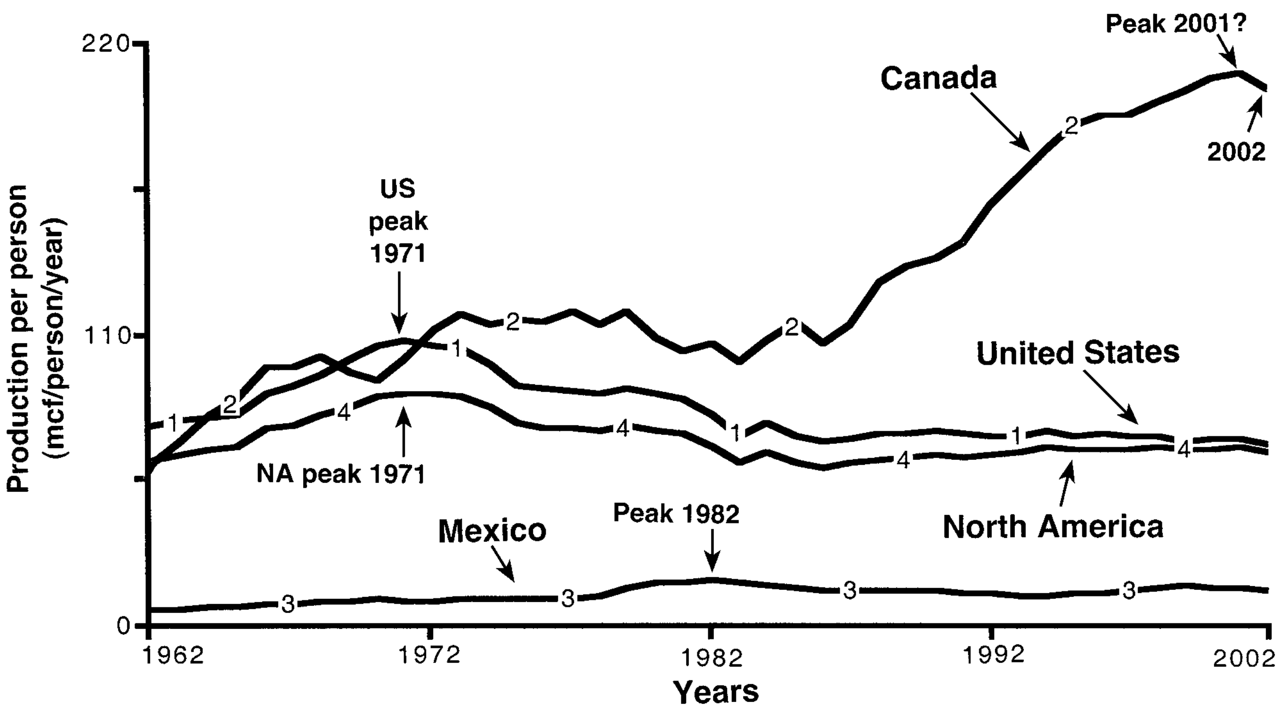

Figure 2. Natural gas production per person: United States, Canada, Mexico, and North America.

United States

In 1971 United States population was 207 million. It increased to 288 million in 2002, a growth rate of 1.1 percent/y. Meanwhile, U.S. gas production declined at 0.4 percent/y. The net result was that United States gas production per person peaked at 106.2 mcf/y in 1971, then fell to 67.2 mcf/y in 2002 –an average decline of 1.5%/y during 31 years (Fig. 2, curve 1).

Canada

Canada's population was 22 million in 1971 and grew to 32 million in 2002–a growth rate of 1.2%/y. At the same time, Canadian gas production increased by 3.2%/y. The net result was that Canadian gas production per person grew from 99.3 mcf in 1971 to 203.1 mcf in 2002, an average growth of 2.2%/y (Fig. 2, curve 2). The change in Canada's gas production per person in recent years is noteworthy. From 1986 to 1995 it soared by 6.3%/y, but from 1995 to 2002 it slowed to 1.0%/y. Although there is modest population growth included in these figures, most of the decline in per capita gas production was the result of the decline in rate of growth of gas production. Canada's gas industry is maturing.

Mexico

Mexico's population was 54 million in 1971 and soared to 103 million in 2002–a growth rate of 2.0%/y. Meanwhile Mexico's gas production increased by 3.1%/y. The result was that gas production per person rose from 7.8 mcf in 1971 to 11.9 mcf in 2002, an average growth of 1.3%/y (Fig. 2, curve 3). However, during this interval gas production per person reached an interim high of 15.7 mcf in 1982, and then fell to 11.9 mcf in 2002, an average decline of 1.4%/y for 20 years.

North America

In North America as a whole, population was 284 million in 1971 and increased to 423 million in 2002, a growth rate of 1.3%/y. Natural gas production increased by 0.3%/y. The result was that annual gas production per person reached 86.8 mcf in 1971 and then fell to 63.9 mcf in 2002, a decline of 1.0%/y (Fig. 2, curve 4). Ranked by gas production per person in 2002, Canada led with 203.1 mcf, United States second with 67.2 mcf, and Mexico third with 11.9 mcf.

Population growth has triumphed over gas production, and at the current rate of growth, North America's population will double to 838 million by 2054. There is no expectation that North American population will either stabilize or decline during this period. It will grow, and now and henceforth the gas problem is supply, not demand (Jerhl, 2001).

CURRENT GAS SITUATION IN NORTH AMERICA

Around the world huge amounts of gas have been discovered. Given the greater variety of geological environments in which gas occurs as compared with oil, there is more gas to be discovered. However, North America has become a more maturely explored area where more than one million gas wells have been drilled. The largest potential gas region in Canada, the Western Canada Sedimentary Basin (WCSB), is becoming extensively exploited, as is onshore United States and parts of the Gulf of Mexico (GOM).

In spite of intensive recent drilling, gas production in both the United States and Canada is declining. Peak yearly gas production (22.0 tcf) in the United States was reached in 1971. In 2002 production was 19.3 tcf. After a decade of strong growth, Canada's production declined in 2002, and in 2003 continued to decline. In 2002 production was 6.5 tcf, and is expected to drop to 5.8 tcf by 2004 unless some unusually large discoveries are made (Potential Gas Committee, 2003). Mexico has had modest gas production. Showing relatively slow growth from 1990 to 1995, it gradually climbed to 1.3 tcf by 1999 but declined to 1.2 tcf in 2002. All North American gas production at present is in decline. Can this trend be reversed?

IMPACT OF DEPLETION RATES

In both the GOM, and onshore United States and Canada, first year gas well depletion rates now may be as much as 50% or more (some as high as 83%), settling down after about two years to 20 to 28%. As total gas production is declining, these depletion rates indicate the industry must run faster just to maintain production, with a further increment in drilling rate to meet projected increased demand.

The impact of high depletion rates of natural gas wells is shown by the fact that, overall, wells less

Table 1. U.S. Yearly Production Additions Per Drilling Rig

Year	Production Additions (mmcfpd)	Baker Hughes Natural Gas Rig Count	Prod'n Adds/ Gas Rig (mmcfpd/rig)
1989		403	
1990	9,795	463	21.2
1991	8,490	351	24.2
1992	8,477	329	25.8
1993	10,082	364	27.7
1994	11,876	426	27.9
1995	9,701	385	25.2
1996	11,378	465	24.5
1997	11,664	563	20.7
1998	12,779	561	22.8
1999	11,484	494	23.2
2000	12,702	719	17.7
2001	13,066	937	13.9
2002E	11,559	691	16.7

Source: Baker Hughes, EIA, Lehman Brothers (2003).

than three years old now account for about 60% of the United States production (Jerhl, 2001; Simmons, 2002). In a detailed statistical study of gas wells in 91 Texas counties Simmons reported: "The 91 counties whose combined gas production totaled 34 percent of the state's total supply suffered a 26 percent decline over the course of 12 months, even during Texas' greatest drilling boom" (Simmons, 2002).

Clearly the pace of drilling must substantially increase. The urgency of this is emphasized by the fact that in 2001 some 21,000 wells were drilled in the United States, but gas production declined by 1.8% in 2002. Table 1 shows the trend of the amount of gas discovered per drill rig from 1990 to 2001, with 2002 estimate. The decline per rig probably is the result of a decline in size of reservoirs being discovered, a mark of a maturely explored region. The same trend is taking place in Canada. Large gas fields are discovered early because they are big. Subsequent drilling locates smaller and smaller fields. Riva (1997) reported that in the United States in 1973, about 124,200 wells averaged 182 mmcf/y (million cubic feet per year) per well. In 1997 the average lower 48 states annual per-well production was 60 mmcf/y from just over 294,000 wells.

The EIA (2003) for the United States states: "A key question facing producers and policy makers today is whether natural gas resources in the lower 48 states have been exploited to the point at which more rapid depletion rates eliminate the possibility of increasing—or even maintaining—current production levels at reasonable cost."

GAS POSITION AND OUTLOOK BY COUNTRY

Canada

Canada's gas production grew rapidly from 7.6 bcfd (billion cubic feet a day) in 1986 to 15.8 bcfd in 1996, then the production growth rate slowed down reaching 17.8 bcfd in 2002, with 95% of it coming from the WCSB lying chiefly in western Alberta and eastern British Columbia.

The Alberta Energy and Utility Board (AEUB) in its 2001 report on supply outlook for 2001 to 2010 predicted conventional gas production in Alberta will peak by 2003 at 5.5 tcf (Nikiforuk, 2001). The AEUB also stated the reserve/production ratio of Alberta gas declined from 30 in 1992 to 8 in 2001. In 2002, Alberta production declined 4%, and is expected to continue to decline slightly in 2003.

Canadian frontier areas are north, both onshore and offshore, off the East Coast, and offshore British Columbia. This last area, heretofore banned from exploration, now is under consideration for development, with an estimate of up to 42 tcf of gas in place. No estimate is made of recovery factor (World Oil, 2003b). Both onshore and offshore northern and eastern Canada have had a modest amount of exploration with more projected. Initial successes in eastern Canada were encouraging, but subsequent drilling has had mixed results, causing some doubts about the size of the resource (Cattaneo, 2003).

Canada's National Energy Board in 2003 predicted natural gas production will drop during the next two years, noting that this will put upward pressure on prices, giving a sense of urgency to plans for United States LNG imports. Production in Canada declined 1.8% in 2002 and is expected to decline a further 1.6% in 2003. This is important to the United States as Canada now is by far its largest gas supplier, shipping 56% of its production to the United States, making up 15% of United States 2002 supply.

In the WCSB, which now produces 95% of Canada's gas, it is significant to note the trend of initial production of wells being completed as compared with the past. Initial production averaged 775 mcfd (thousand cubic feet a day) in 1991 and 375 mcfd in 2001. Production also declines more rapidly in the new wells, the first two years averaging 50% annually as compared with 20% for wells drilled in 1991. This is probably the result of better completion methods allowing faster recovery, and smaller gas reservoirs being discovered. Now in the WCSB after the first two years, well production declines average 20%. The U.S. Potential Gas Committee makes the observation on Canada's situation: "Consequently the natural gas industry must drill many more wells than before just to maintain overall deliverability." In 1995, 11,062 gas wells were drilled. This number increased in 2001 to 17,983, a record to that time.

As of year-end 2001, Canada's proved gas reserves were 60.1 tcf. The Canadian Gas Potential Committee (2001) estimates the total of discovered, undiscovered, and proved reserves were 233 tcf at year-end 2001. There are, however, additional conceptual plays not included in this estimate which could raise the total by 14 to possibly 21 tcf, to a grand total of 247 to 254 tcf. This compares with the average estimated total gas possible in the United States of 1,549 tcf.

Canada has substantial coalbed gas prospects with exploration in its early stages. Several pilot projects are underway, and one project has been brought on line in southern Alberta. Estimates by the Canadian Gas Potential Committee give a range of 187 to 568 tcf total gas-in-place for ten prospective areas. Recovery factors are estimated to be between 20 and 50%.

Canada's gas production apparently has peaked, at least temporarily, and with a rising population and increased industrialization, Canada's internal demand for gas is growing. One notable factor in the increase is the need for gas in oil production processes both for the oil sands north of Fort McMurray (the Athabasca area), and the heavy oil of the Cold Lake-New Westminster area of eastern Alberta and western Saskatchewan. These are basically manufacturing operations and not geological exploration projects. Both require large amounts of heat energy.

There is increasing use of the steam assisted gravity drainage (SAGD) *in situ* production process for the oil sands which is environmentally more acceptable than the conventional mining process. It disturbs less land surface, and uses less water than does the open pit strip mining operation. But, as with the conventional oil sand process, it also uses natural gas as the heat source as now designed. It has been projected that by 2020, 25% of Alberta's natural gas production will have to be used in oil sand and heavy oil operations if the expected expansion of these projects is to be achieved. Emphasis will have to be on increasing this production, for conventional oil production has peaked in Canada, and remaining reserves are less than 5 billion barrels. Recognizing the great importance of oil sands (estimated 310 billion barrels recoverable) and heavy oil to Canada's energy future, and with the prospect that Canada's gas supplies cannot meet all the demand, discussions have been held on the possibilities of building atomic energy plants to provide the process heat. This may eventually happen, but surely is a decade or more in the future. In the meantme, gas will have to provide the process heat.

United States

The United States consumption of natural gas was 19.5 tcf in 1990 and reached 23.6 tcf in 2002. This rising demand trend is expected to continue. Gas reserves dropped from 290 tcf in 1970 to 184 tcf at year-end 2002. Increased drilling since 1994 resulted in a slight upward trend in proved reserves from 164 tcf in 1994 to 184 tcf in 2002 not including coalbed gas.

The Potential Gas Committee recognizes seven gas regions in the United States. These, with their estimated gas resources, are shown in Table 2.

Adding what the Potential Gas Committee terms *Possible and Speculative*, a figure of total gas for the United States is 1,127 tcf. A comprehensive summary by Curtis and Montgomery (2002) of several recent estimates gave an average figure of 1,549 tcf which is approximately 8 1/2 times proved reserves. The EIA estimates total technically recoverable natural gas resources of the United States at 1,288 tcf, as shown in Table 3. All three estimates are similar.

The largest category of unproved resource estimated at 445 tcf is unconventional gas of which 71% is in tight sandstones. Much of this is in deep basins in the Rocky Mountains where access to areas for

Table 2. U.S. Conventional Potential Gas Resources by Region

Region	Conventional Potential Gas Resources (Tcf)
Atlantic	103.9
North Central	22.0
Gulf Coast	292.8
Mid-Continent	116.9
Rocky Mointains	175.1
Pacific	52.5
Total 48 states	763.2
Alaska	143.0
Total 50 states	906.2
Coalbed methane	17.1
Grand total	923.3

Source: Report of Potential Gas Committee December 31, 2002.

Table 3. EIA Estimates of U.S. Technically Recoverable Gas Trillions of cubic feet

Proved reserves	183
Undiscovered onshore and offshore nonassociated	269
Inferred nonassociated	222
Unconventional (tight gas, shale gas, coalbed gas)	445
Other unproven (asociated dissolved)	169
Total	1,288

Source: EIA Annual Energy Outlook 2003.

explorations is the result of environmental concerns and has been a problem (Shirley, 2003). "Other unproven" includes 32 tcf in Alaska and 137 tcf in lower 48 crude oil reservoirs.

A substantial amount of the gas in tight sandstones is deep gas defined as reservoirs below 15,000 feet. Ultradeep gas is defined as occurring at depths greater than 25,000 feet. These deposits occur in conventional or in unconventional (continuous type) basin-center accumulations which basically are single fields with large extent.

The USGS in 1995 estimated that nearly 114 tcf of technically recoverable gas remains to be discovered from deep sedimentary basins. The success rate of deep wells is about 25%. Costs may run as much as ten times that of shallower wells. Increased problems of high temperatures and pressures, and increased quantities of acid gas such as CO_2 and H_2S are added hazards of deep drilling. Nevertheless, deep drilling in the Anadarko Basin, the Permian Basin, and the Gulf Coast offshore has discovered significant production. Basins in the Rockies and Colorado Plateau are less tested, and offer a significant frontier. With the recent increase in gas prices there is a revival of interest in subbasalt prospects of the Columbia Plateau of Washington where earlier minor drilling encountered gas, at the time uneconomic.

As of 1998, of the 20,572 wells in the United States drilled deeper than 15,000 feet, 11,532 were producing gas and oil. Of these, 5,119 were completed at total depth. The others were producing gas or oil from shallower depths, both above and below 15,000 feet (Dyman and others, 2003). Deepwater Gulf and deep onshore basins are the key to significantly increasing domestic supply.

Coalbed methane currently is the fastest growing gas play in the United States, and now produces about 9% of supply. The estimated resource base is large, most of it in the Rocky Mountain states, which now produce 80% of the gas. The wells are shallow and inexpensive to drill. In some areas the coal can be reached at less than 300 feet with truck-mounted rigs (as in the Powder River Basin) where the wells cost about $65,000. The finding cost is 16¢/mcf, with average per well reserves of 400 mmcf. In other places the costs can be substantially higher. Nevertheless, the play is economic, and some wells are productive. A well in New Mexico has produced more than 35.3 bcf (Lyle, 2000).

The coal must be dewatered. As the water is pumped out, methane is released from the coal and production gradually rises. There are, however, increasing environmental concerns. Dewatering the coal beds can result in lowering the regional water table. Water from dewatering the coal and discharged at the surface has had negative effects in some areas, causing local resistance to further development (Harden and Jerhl, 2002). Nevertheless, the coalbed methane play is continuing to grow, with more than 50,000 wells projected to be drilled the next several years.

The United States has not been self-sufficient in gas since 1971. The EIA states: "A major consideration for energy markets through 2025 will be the availability of adequate natural gas supplies at competitive prices to meet growth in demand . . . Total demand for natural gas is projected to increase at an annual average rate of 1.8 percent between 2001 and 2025 from 22.7 trillion cubic feet to 34.9 trillion cubic feet primarily because of rapid growth in demand for electricity generation."

Despite whatever increased drilling may be accomplished in the United States, it is unlikely that gas demand can be met domestically. The EIA projects: "Domestic natural gas consumption is met by domestic production and imports." All published forecasts show domestic production providing a decreasing share of gas supply.

Mexico

At present, Mexico is not self-sufficient in gas and imports a small quantity (0.3 tcf in 2002) from the United States. At year-end 2001, the gas reserve estimate by Mexico was 29.5 tcf, but in order to comply with United States Securities and Exchange Commission guidelines, the estimate was revised to 8.8 tcf at year-end 2002. At the same time oil and condensate reserves were reduced from from 26.9 billion barrels to 12.6 billion barrels.

Gas demand in Mexico to 2010 has been projected by the Potential Gas Committee: "Industrial use and power generation are expected to increase Mexico's demand for natural gas by 14 percent annually. Demand is expected to rise to 9 Bcfd by 2010. Domestic supply will be unable to meet that demand, even with new production targeted to come on line. Significant gas shrinkage and fuel losses occur during the production of oil. Therefore, Mexico will be looking at increasing its pipeline gas imports from the U.S. by fourfold by 2009" (Potential Gas Committee, 2003).

Although Mexico expects to increase gas production, it is not likely to be self-sufficient in gas in the foreseeable future, and therefore must depend on imports from the United States and LNG. Mexico has plans to build several LNG terminals on both coasts (Case, 2003). In 2003 the Mexican Energy Regulatory Commission awarded a natural gas storage permit to Marathon Oil Corporation and partners to build an LNG receiving station in Baja, California, near Tijuana. Some of this gas may be piped to California.

Mexican coalbed methane prospects have not yet been evaluated. But the known high gas content of some coal beds, and proximity to major population centers suggest that this source of gas could be of at least modest economic importance.

OPPORTUNITIES AND LIMITATIONS

The future of North American gas offers both opportunities and limitations. Opportunities lie in the regions relatively undeveloped, and in accessing developed gas now stranded (e.g., Alaska North Slope). The frontiers are both horizontal and vertical. There are new areas to explore, and deeper drilling to be done in both developed and undeveloped regions. Additional opportunities include the potential of increased production of unconventional gas, chiefly coalbed methane, tight sand reservoirs, shale gas, and the possibility that gas hydrates may eventually become commerically viable. There also are research and development frontiers whereby previously overlooked gas deposits can be discovered, and production techniques developed for gas reservoirs now uneconomic.

Limitations to increasing gas supply include governmental and environmental factors restricting access to potentialy productive gas areas, raising sufficient capital, and the need to develop an adequate supply of well-trained talent for industry. The economics of the gas industry also must be considered in terms of what factors will make for both a floor and a ceiling for gas prices. With LNG imports being the marginal supply for the future against a rising demand, the gas price would not go below the price for which LNG can be landed. LNG imports combined with North American production may not be sufficient to meet the demand, and the ceiling price for gas would be where that price dampens demand to meet available supplies. Local critical shortages could develop with resultant brief price spikes.

OTHER CONSIDERATIONS

Stranded Gas and Pipelines

The areas of stranded gas needing pipeline outlet are the Alaska North Slope, the Mackenzie Valley/Beaufort Sea (which includes the Mackenzie Delta) areas, the Jeanne d'Arc Basin off the coast of Newfoundland, and the Canadian Arctic islands.

Alaska North Slope reserves are estimated at 35 tcf with an additional 16 tcf to be developed giving a total of 51 tcf to support the line. Routes for the Alaska stranded gas are under discussion. The estimated cost of the pipeline is $20 billion or more, and would carry about 4 to 5 billion cubic feet a day. A $3.48 mcf lower-48 wellhead price is the estimated trigger price to justify it. Completion of that project is probably at least a decade away. The EIA projects it coming on line in 2021.

The Mackenzie Valley/Beaufort Sea areas and the Mackenzie River corridor upstream from the delta have an estimated total of 85 tcf to support the line (D. W. Axford, pers, comm., 28 July 2003). Exploration and drilling are proceeding to develop these resources (Lyle, 2003b). Design work now is underway for the 800-mile $4 billion pipeline, to link this region to the main TransCanada PipeLines network, with a possible completion date of 2008. A floor of $3.37 mcf is estimated to economically justify it, and this requirement seems likely to be more than met. (All reserves, estimated additions, pipeline costs, and trigger prices for Alaska and Canada gas are from EIA 2003, and in U.S. dollars).

Gas Hydrates

Gas hydrates (also termed gas clathrates) remain the tantalizing elusive energy of the gas industry (Haq, 1998). Gas hydrates occur worldwide. "If current estimates are correct, gas hydrates contain more potential fossil fuel energy than occurs in conventional oil, gas, and coal deposits" (Kvenvolden, 1993). The United States, Canada, Japan, Russia, India, and several other countries are investigating the possibilities of production from hydrates. Opinions both in and out of industry run the full spectrum as to the future prospects of commercial gas from gas hydrates. At least one major company has written them off for the foreseeable future. Others have positive views, and investigations continue. From Canada is a recent report that in the Mackenzie Delta a gas hydrate well flared gas, which brought the optimistic view that this area could see small commercial methane production from hydrates within a few years.

Extensive gas hydrate deposits are known off the southeast United States coast, in the Gulf of Mexico, offshore Oregon, in the Arctic coastal regions of both the United States and Canada, and off the east and west coasts of Mexico (Kvenvolden, 1993). The USGS has suggested that 38,000 tcf are trapped in the GOM hydrates, and 590 tcf are in the Alaska North Slope. The United States Methane Hydrate Research and Development Act of 2000 (Public Law 106–193) provided modest funds for hydrate exploration, and projects are underway on the Alaska North Slope (World Oil, 2003a; Snow, 2003; Moritis, 2003). However, for at least the next decade and probably for some time beyond it is unlikely that gas hydrates can be a significant part of North American supply. The potential volumes of production being so large, however, hydrate research is continuing (Fischer, 2000; U.S. Geological Survey, 2001).

Elasticity of Demand

The demand for gas for at least the next few years seems to be beyond what can be met for present uses. The volumes of various United States gas uses in 2001, with projected uses for low and high economic growth for 2015 are shown in Table 4.

Note that the largest increase is for electricity generation with a 45% increase over 2001 in the low growth scenario, and a 62% increase in the high growth scenario. The EIA also assumes that the domestic gas production will increase from 19.36 tcf in 2001 to 23.08 tcf in 2015 for the low growth scenario and to 24.06 tcf for the high growth scenario. This is a huge challenge for industry. During this time imports of both Canadian gas and LNG are presumed to increase. This assumption by the EIA that Canadian gas imports can increase during this period is not shared by at least some Canadian gas producers (D. W. Axford, pers. comm., 10 June 2003). Also, a study by the Canadian Energy Research Institute, Calgary, suggests that "... reliance on Canadian reserves to fill the gas demand gap in the US may be misplaced" (Oil & Gas Journal, 2000). Regarding help for the United States from Canada's gas production, Simon (2003) states "... the days when America could look north for relief are over."

Table 4. U.S. Natural Gas Demand by Sector as of 2001 and Estimated 2015 Trillion Cubic Feet

	Actual 2001	2015 Low Economic Growth	2015 High Economic Growth
Residential	4.81	5.60	5.78
Commercial	3.25	3.84	3.95
Industrial	7.53	9.00	10.24
Electricity generation	5.26	7.63	8.51
Other	1.79	2.30	2.43
Total	22.64	28.38	30.90
Net imports	3.64	5.40	7.58

Source: Energy Information Administration, 2003.

If United States gas demands cannot be met, where then is the elasticity of demand? There is little elasticity in use of gas for household purposes. This use probably would have priority if supplies were allocated, as switching to other fuels would be difficult. Power generation has some elasticity. Industry has the greatest elasticity, but with higher gas prices, some might have to simply shut down, or see their profit margins reduced to remain competitive (Vasnetsov and Kovenya, 2003). The United States chemical industry uses 11% of all natural gas consumed in the United States as feedstock material and to run their plants. Already higher gas prices are taking their toll. "U.S. chemical companies are closing plants, laying off workers and looking to expanded their own production abroad" (Herrick, 2003). This can have the unfortunate result of increasing the need for imports of such things as ammonia fertilizer from regions which have cheaper natural gas. This exacerbates the United States already large negative international balance of payments, and places more pressure on the value of the dollar.

A number of countries, notably the Persian Gulf nations, are expanding their petrochemical operations producing a variety of products using natural gas as the raw material which already are competing with similar North American industries. Some North

American petrochemical operations, however, have the ability to switch from natural gas to liquid propane and naptha, products derived from oil, and which may be less expensive than natural gas.

LNG

Since 1990, LNG imports to the United States have grown from 39 billion cubic feet annually to 169 billion cubic feet in 2002. In perspective, the United States in 2002 used about 65 billion cubic feet of gas a day. LNG in 2002 supplied less than 1% of United States gas demand.

Speakers at a Cambridge Energy Research Associates conference in Houston in early 2003 predicted that "North American natural gas supplies will decline this year and pick up slightly in 2004 and 2005, and then go into a permanent decline, forcing increasing supplies of liquefied natural gas (LNG) to make up the deficit . . ." (Lyle, 2003a). There are four LNG terminals in the United States, three are operational and the fourth is being put back into service.

At least 16 possible LNG terminal sites to supply the United States are being investigated. Nine are projected for the United States mainland, and two offshore. Permits were issued in 2003 for two locations in Texas. Some possible mainland United States sites are meeting environmental opposition. To mitigate this problem for United States supply, three are projected in the Bahamas (with pipelines to Florida), and four are projected for northern Mexico. Total capacity if all were built would be 5.36 tcf annually (EIA, 2003). Average trigger price to justify new LNG facilities is estimated at $3.99 mcf (2001 dollars). No LNG facilities now exist in Mexico or Canada. Both are considering LNG sites to supply domestic demand. LNG receiving terminals cost up to one billion dollars. LNG tankers cost up to a half billion dollars, but costs are being reduced somewhat as fabrication of LNG tankers is becoming a mass production venture with associated financial savings.

Worldwide, there is a major move to substantially increase LNG shipping capacity with tankers and terminals under construction (Sen, 2003). The EIA and others anticipate LNG will be a growing part of North American gas supply. "Imports of LNG will play an increasingly important role in meeting US demand for natural gas . . ." (Fletcher, 2003). LNG may be more important than expected, for the anticipated growth in supply from Canada may not materialize.

Table 5. North American Natural Gas: Net Imports, Consumption, Consumption Per Person, and Imports as a Percent of Consumption

Year	Net Imports (Tcf)	Total Consumption (Tcf)	Consumption/ Population (mcf/person)	Imports/ Consumption (%)
		United States		
1990	1.444	19.50	78.0	7.40
1992	1.860	20.59	80.2	9.03
1994	2.432	21.59	82.0	11.26
1996	2.743	22.93	85.0	11.96
1998	3.022	22.67	82.1	13.33
2000	3.584	23.78	87.2	15.07
2002	3.540	23.56	81.9	15.02
		Canada		
1990	−1.408	2.36	84.8	−59.71
1992	−1.963	2.53	88.7	−77.56
1994	−2.450	2.78	95.1	−88.08
1996	−2.782	3.01	100.4	−92.39
1998	−3.036	3.00	97.8	−101.30
2000	−3.526	2.93	93.7	−120.35
2002	−3.630	2.85	89.3	−127.43
		Mexico		
1990	0.004	0.96	11.4	0.42
1992	0.099	1.02	11.6	9.70
1994	0.011	0.95	10.5	1.15
1996	0.018	1.01	10.7	1.78
1998	0.032	1.25	12.9	2.56
2000	0.104	1.36	13.5	7.65
2002	0.259	1.49	14.4	17.43
		North America		
1990	0.040	22.82	63.0	0.18
1992	−0.004	24.15	64.8	−0.02
1994	−0.007	25.32	66.1	−0.03
1996	−0.021	26.95	68.5	−0.08
1998	0.018	26.92	66.6	0.07
2000	0.162	28.07	67.8	0.58
2002	0.169	27.90	66.0	0.61

MEXICO, UNITED STATES, AND CANADA IMPORT HISTORY

Table 5 shows North American net imports, total consumption, consumption per person, and imports as a percent of consumption from 1990 to 2002. During this time less than one percent of gas imports came from outside the continent.

Most of the imports are internal with the United States importing gas from Canada, and Mexico importing a small amount of gas from the United States. Canada to date has been a net exporter in all years, showing negative imports. This may eventually change, as Canada also is looking toward LNG imports. North America appears to be losing its natural gas self-sufficiency.

CONCLUSIONS

Natural gas prices in North America seem to have risen to a new plateau, caused by a demand-supply gap which cannot be adequately filled, at least in the near term. The roller-coaster rides of demand and price volatility are largely behind us. Replacing those times will be a steady strong market with possible price spikes resulting from local shortages. Continued population growth along with advantages which gas has over competing fuels ensure household, industrial, and power-generation rising demand for gas. Eventually LNG imports may mitigate our supply problem to some degree, but that is unlikely to occur for several years.

Access to areas for exploitation will be a continuing problem. But with rising prices will come an increasing public awareness of the fact that, unlike oil, for the next decade at least and probably beyond, we are largely on our own in terms of natural gas supplies. Imports will gradually increase, but domestic sources are our mainstay. Access to them is vital to our economic health. Publicizing these facts along with the higher costs of moving into frontier areas, including deeper drilling, should be an essential part of the industry's agenda.

For several years ahead at least the North American gas supply situation would seem to be tight. If economic disruptions are to be avoided, the following matters must be recognized and addressed:

- The days of cheap gas are history.
- Areas now off limits such as portions of the Rocky Mountains, the Gulf of Mexico, and the Arctic Slope must be accessed.
- Investment capital must be raised and employed in exploration and drilling under reasonable tax policies.
- Competent personnel must be identified and trained.
- The number of drill rigs in operation must be increased, especially larger rigs for deeper drilling.
- Pipelines to stranded gas must be constructed.
- Additional LNG facilities must be built.
- All these elements must begin to come together starting now. There is little "cushion" leeway in these matters.

There probably is more gas yet to be discovered than has been produced. But to produce it, drilling activity beyond previous records must occur. Busy times lie immediately ahead for the North American natural gas industry.

ACKNOWLEDGMENTS

Reviewing this paper by industry professionals is much appreciated. In the United States we acknowledge T. L. Bezzerides, Louis Bortz, L. F. Ivanhoe Robert Lent, and Alistair McCrone. We were pleased to have the comments of Donald Axford and Frederick Calverley of Calgary, Alberta with their long experience and expertise on Canada gas. Jay Hanson, from his studies, early expressed to us his concern about North American gas supplies and encouraged this study. Marvin Gregory supplied numerous items of information we might not otherwise have seen. Jean Laherrere of France has been a steady source of basic data, and we benefited from his creaming curve graphs as we examined the North American gas scene. Editorial suggestions by L. R. Kittleman have been very helpful.

REFERENCES

Adkins, J. M. 2003, Raymond James' energy "Stat of the Week:" Raymond James & Associates Inc., May 19, 4 p.

British Petroleum, 2003, BP statistical review of world energy, 41 p. For complete database see www.bp.com/.

Canadian Gas Potential Committee, 2001, Natural gas potential in Canada 2001: Can. Gas Potential Committee, 2001, 113 p.

Carson, M. M., 1997, Natural gas central to world's future energy mix: Oil & Gas Jour., v. 95, no. 32, p. 37–50.

Case, B. M., 2003, Power-hungry Mexico mulls gas imports: The Dallas Morning News, June 6.

Cattaneo, C., 2003, "Time out" casts doubt on East Coast plays: Financial Times, February 15.

Curtis, J. B., and Montgomery, S. L., 2002, Recoverable natural gas resources of the United States: Summary of recent estimates: Am. Assoc. Petroleum Geologists Bull., v. 86, no. 10, p. 1671–1678.

Durham, L. S., 2003, The future appears to be gas-fired: Am. Assoc. Petroleum Geologists Explorer, v. 24, no. 2, p. 12–14.

Dyman, T. S., and others, 2003, Deep natural gas resources: Natural Resources Research, v. 12, no. 1, p. 41–56.

Energy Information Agency, 2003, Annual energy outlook 2003 with projections to 2025: U. S. Dept. Energy, 256 p.

Fischer, P. A., 2000, Gas hydrates research continuing to increase: World Oil, v. 221, no. 12, p. 66–67.

Fletcher, S., 2003, LNG imports to be key source of future US gas supplies: Oil & Gas Jour. v. 101, no. 8, p. 35–36.

Harden, B., and Jerhl, D., 2002, Ranchers bristle as gas wells loom on the range: The New York Times, December 20.

Haq, B. U., 1998, Gas hydrates: greenhouse nightmare, energy panacea, or pipe dream?: GSA Today, v. 8, no. 11, p. 1–5.

Herrick, T., 2003, Gas prices rock chemical industry: The Wall Street Journal, June 18.

IDB, 2003, International Data Base, summary demographic data, www.census.gov/.

Jerhl, D., 2001, Boom in natural gas drilling can't match soaring demand: The New York Times, July 22.

Kvenvolden, K. A., 1993, A primer on gas hydrates: The future of energy gases: U.S. Geol. Survey Prof. Paper 1570, p. 279–298.

Lehman Brothers, 2003, Plummeting supply to drive gas demand down, prices up: Lehman Brothers Global Equity Research, 26 p.

Lyle, D., 2000, Coalbed methane fuels growth: Hart's E&P, October, p. 17–18.

Lyle, D., 2003a, North America gas starts to slide: Hart's E&P, April, p. 123.

Lyle, D., 2003b, Operators prepare Mackenzie Delta production: Hart's E&P, June, p. 69.

Moritis, G., 2003, Seeking flammable ice: Oil & Gas Jour. v. 101, no. 21, p. 15.

NERC, 2003, Summer assessment: Reliability of the bulk electric supply in North America: North American Electric Reliability Council, May, Appendix 1, www.nerc.com/.

Nikiforuk, A., 2001, The next gas crisis: Canadian Business, August 20, p. 28–30, 39.

Oil & Gas Journal, 2000, Canadian reserves may not fill the gas demand gap in the US: Oil & Gas Jour. v. 98, no. 49, p. 7.

Potential Gas Committee, 2003, Potential supply of natural gas in the United States: Colorado School of Mines, Golden, 316 p.

Riva, J. P., Jr., 1997, U.S. conventional wisdom and natural gas: Hubbert Center Newsletter 97/3, Colorado School of Mines, Golden, 4 p.

Sen, C. T., 2003, LNG poised to consolidate its place in global gas trade: Oil & Gas Jour. v. 101, no. 24, p. 72–81.

Shirley, K., 2003, Rockies an access 'battleground': Am. Assoc. Petroleum Geologists Explorer, v. 24, no. 5, p. 24, 26, 30.

Simmons, M. R., *in* Lyle, D., 2000, US gas demand to hit 40 Tcf by 2015: Hart's E&P, May, p. 17.

Simmons, M. R., 2002, The case for a coming gas shortage: World Energy, v. 5, no. 3, p. 58–65.

Simon, B., 2003, Canada is losing ability to fill U.S. gas needs: The New York Times, June 26.

Snow, N., 2003, Alaska well aims at hydrate deposits: Hart's E&P, June, p. 63–64.

U.S. Geological Survey, 2001, Natural gas hydrates–vast resource, uncertain future: U.S. Geol. Survey Fact Sheet FS-021–010, 2 p.

Vasnetsov, S., and Kovenya, Z., 2003, Higher natural gas prices will decrease profitability of US petrochem industry: Oil & Gas Jour. v. 101, no. 17, p. 52–55.

World Oil, 2003a, Innovative Arctic platform: World Oil, v. 224, no. 5, p. 19.

World Oil, 2003b, British Columbia prepares to open previously banned offshore areas: World Oil, v. 224, no. 7, p. 41.