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THE DOMESTIC NATURAL GAS INDUSTRY IN DEVELOPING COUNTRIES

by

Donald L. Klass
Institute of Gas Technology
Chicago, Illinois U.S.A.

Riaz A. Khan
and
Salahuddin Khwaja
The World Bank
Washington, D.C. U.S.A.

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3424 South State Street Chicago, Illinois 60616

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Donald L. Klass
Institute of Gas Technology
Chicago, Illinois 60616, U.S.A.

Riaz A. Khan
The World Bank

and

Salahuddin Khwaja
The World Bank
Washington, D.C. 20433, U.S.A.

ABSTRACT

The domestic natural gas industry has generally exhibited slow growth in most developing countries that are fortunate enough to have sufficient proved gas reserves to meet energy needs. But supportive government policies that promote the use of indigenous reserves are now beginning to have a positive impact in many parts of the world. Supply and distribution infrastructures are being built or modernized. And natural gas is now or will be available at prices that encourage the displacement of competitive fuels in the larger, energy-intensive industrial and power-generation markets of these countries. It is expected that the domestic gas industry in many developing countries will expand at higher rates than in the past. In the next few decades, the resulting benefits will include reductions in oil consumption per capita, improvements in the balance of payments for oil-importing and exporting developing countries, greater efficiency of energy usage and lower energy consumption per output unit, and improved environmental quality. The national economies and living standards will also undergo significant advancement.

THE DOMESTIC NATURAL GAS INDUSTRY IN DEVELOPING COUNTRIES

INTRODUCTION

Most industrialized countries have made extensive use of fossil fuel reserves as primary energy resources, and many correlations have been developed by energy analysts between increasing domestic energy consumption and the growth of gross domestic product. Some have concluded that the ready availability of fossil fuel resources has been the driving force behind much of this growth. Unfortunately, not all countries have sufficient fossil fuel reserves nor have those that do necessarily made good use of them. This is especially evident for many of the developing countries of the world,* which currently comprise about 78 percent of total population.

Analysis of current proved reserves, production, and consumption data for coal, oil, and natural gas supports this contention. On an energy content basis, and assuming present reserves relationships continue, the data in able1 show that Africa, Asia, and South America have about 55 percent of the world's coal reserves, mainly in Asia which has about 50 percent. But these regions only have 17 to 18 percent of the world's oil reserves; the Middle East alone has about 67 percent. Similar analysis of the production and consumption data presented in Tables 2 and 3 suggest that the developing countries produce and consume about one-third of the world's production of coal and, surprisingly, oil.** But they only produce and utilize about one-tenth of the world's natural gas production.

A more detailed analysis of proved reserves, production, and consumption of natural gas can be made by examination of the data for the individual countries listed in Table 4. Analysis of these data shows that although the developing countries have about 40 percent of the world's proved gas reserves, over 60 percent of natural gas production and consumption in 1989 by developing countries was attributable to only 10 of all the developing countries. These countries are Algeria, Argentina, China, Hungary, Indonesia, Iran, Mexico, Pakistan, Poland, and Venezuela; each consumed more than 420 x 10^9 CF of natural gas in 1989. A quantitative assessment is presented in

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*In this paper, the definition of developing countries used by The World Bank is employed. It includes all countries in Africa, Asia, Latin America, and the Middle East, and Bulgaria, Greece, Hungary, Papua New Guinea, Poland, Turkey, and Yugoslavia, but does not include Abu Dhabi, Brunei, Bahrain, Japan, Kuwait, Quatar, Saudi Arabia, Singapore, and the United Arab Emirates. The gross national product is $5,999 or less per capita for the developing countries.

**Most of the developing countries are located in Africa, Asia, and South America.

Table 1. PROVED COAL, OIL, AND NATURAL GAS RESERVES FOR REGIONS OF WORLD[a]

	Coal[b]		Oil		Natural Gas	
Region	10^6 Short ton	Quad[c]	10^6 bbl	Quad[d]	10^9 CF	Quad[e]
Africa	69,345	1,664	59,892	347	285,143	285
America, North	247,016	5,630	84,618	491	345,567	346
America, South	15,126	413	68,432	397	160,514	161
Asia	881,172	19,765	48,267	280	271,022	271
Europe	441,468	8,534	72,681	422	1,793,115	1,793
Middle East	6,941	5	663,248	3,847	1,325,415	1,325
Oceania	100,374	1,947	1,975	11	27,539	28
World Total	1,761,442	37,957	999,113	5,795	4,208,315	4,208

[a]Source: IGT's Energy Statistics and gasLine®. Summations may not equal arithmetic sums because of rounding.

[b]Coal includes subbituminous, bituminous, and anthracite coals, and lignite.

[c]World average heating values for subbituminous, bituminous, and anthracite coals assumed to be 24 x 10^6 Btu/short ton. World average heating value for lignite assumed to be 14 x 10^6 Btu/short ton. Reserves are for 1987.

[d]World average heating value for oil assumed to be 5.8 x 10^6 Btu/bbl. Reserves are for 1990.

[e]World average heating value for natural gas assumed to be 1,000 Btu/CF. Reserves are for 1990.

Table 2. PRODUCTION OF COAL, OIL, AND NATURAL GAS FOR REGIONS OF WORLD[a]

Region	Coal		Oil		Natural Gas	
	10^6 Short ton	Quad	10^6 bbl	Quad	10^9 CF	Quad
Africa	245	5.87	2,205	12.79	2,202	2.20
America, North	985	23.65	4,243	24.61	24,135	24.14
America, South	39	0.93	1,505	8.73	2,130	2.13
Asia	1,448	34.11	2,049	11.88	4,156	4.16
Europe	2,234	47.89	5,725	33.12	37,830	37.83
Middle East	53	0.80	6,123	35.51	4,241	4.24
Oceania	249	5.51	224	1.30	914	0.91
World Total	5,252	118.76	22,074	128.0	75,608	75.61

[a]Footnotes from Table 1 applicable to this table. Coal, oil, and gas production figures are for 1987, 1990, and 1990, respectively.

Table 3. CONSUMPTION OF COAL, OIL, AND NATURAL GAS FOR REGIONS OF WORLD[a]

Region	Coal		Oil		Natural Gas	
	10^6 Short ton	Quad	10^6 bbl	Quad	10^9 CF	Quad
Africa	154	3.70	779	4.51	1,321	1.32
America, North	892	20.54	6,192	35.91	22,178	22.18
America, South	40	0.95	1,200	6.96	1,838	1.84
Asia	1,486	35.03	3,693	21.42	4,958	4.96
Europe	2,339	45.80	8,103	47.00	38,746	38.75
Middle East	59	0.94	1,746	10.13	3,532	3.53
Oceania	101	1.94	220	1.28	692	0.69
World Total	5,071	108.9	21,933	127.2	73,265	73.27

[a]Footnotes from Table 1 applicable to this table. Coal, oil, and gas consumption figures are for 1987, 1989, and 1989, respectively.

Table 4. NATURAL GAS PROVED RESERVES, PRODUCTION, AND CONSUMPTION FOR COUNTRIES BY REGION[a]

Region	Country	Reserves, 10^9 CF	Production, 10^9 CF	Consumption, 10^9 CF
Africa	Algeria	114,700	1,588	696
	Egypt	12,400	240	254
	Libya	43,000	203	162
	Nigeria	87,400	134	140
	Others	27,643	37	70
		285,143	2,202	1,321
America, North	Canada	97,589	4,267	2,276
	Mexico	72,744	1,333	963
	U.S.A.	166,208	18,358	18,780
	Others	9,026	178	160
		345,567	24,135	22,178
America, South	Argentina	27,000	816	805
	Bolivia	4,149	108	--
	Brazil	4,045	113	114
	Chile	4,100	39	63
	Columbia	4,500	141	177
	Peru	7,082	--	--
	Venezuela	105,688	862	629
	Others	3,950	51	50
		160,514	2,130	1,838
Asia	Afghanistan	--	--	67
	Bangladesh	12,700	--	152
	Brunei	11,200	279	65
	Burma	9,400	--	--
	China	35,300	518	523
	India	25,049	438	318
	Indonesia	91,450	1,383	492
	Japan	--	58	1,628
	Malaysia	56,900	570	299
	Pakistan	19,449	451	462
	South Korea	--	--	100
	Taiwan	--	--	46
	Thailand	5,850	212	191
	Others	3,724	248	614
		271,022	4,156	4,958

Table 4, Continued. NATURAL GAS PROVED RESERVES, PRODUCTION, AND CONSUMPTION FOR COUNTRIES BY REGION[a]

Europe	Austria	--	--	189
	Belgium	--	--	331
	Bulgaria	--	--	246
	Czechoslovakia	--	--	440
	Denmark	4,488	101	54
	Finland	--	--	99
	France	1,324	106	1,042
	Germany	12,400	566	2,905
	Hungary	--	--	421
	Ireland	--	--	74
	Italy	11,624	737	1,527
	Netherlands	60,900	2,618	1,464
	Norway	60,674	897	56
	Poland	--	--	504
	Romania	4,700	1,181	1,454
	Spain	780	--	153
	Switzerland	--	--	62
	U.K.	19,775	1,701	2,095
	U.S.S.R.	1,600,000	28,800	25,094
	Yugoslavia	2,900	--	289
	Others	13,503	1,124	247
		1,793,115	37,830	38,746
Middle East	Abu Dhabi	182,800	--	--
	Bahrain	6,250	210	172
	Iran	600,350	854	735
	Iraq	95,000	141	--
	Kuwait	48,600	148	352
	Oman	7,200	88	90
	Quatar	163,200	265	238
	Saudi Arabia	180,355	1,401	1,069
	Turkey	--	--	106
	United Arab Emirates	--	1,092	646
	Others	41,660	42	125
		1,325,415	4,241	3,532
Oceania	Australia	15,433	750	517
	New Zealand	4,106	164	174
	Papua New Guinea	8,000	--	--
		27,539	914	692
World Total		4,208,315	75,608	73,265

[a]Footnotes regarding natural gas from Tables 1, 2, and 3 applicable to this table. Summations may not equal arithmetic sums because of rounding. "--" denotes either not found or zero.

Table 5.* Natural gas reserves in many developing countries comprise only a small portion of the world's total reserves, but they are often quite large relative to existing and potential domestic markets. The bulk of gas reserves are located in oil-exporting countries; gas reserves also exist in 30 developing countries that import oil.[1] Thus, in many low-income, oil-importing countries, natural gas represents an important resource whose development and use can provide considerable relief to the balance of payments problem and to alleviation of environmental difficulties.

The opportunities that exist for developing countries in Africa, Asia, South America, and the Middle East for expanding domestic natural gas consumption are substantial. Much of the expansion of industrial gas use in these countries is the result of specific policies and projects in gas-rich developing countries that wish to utilize their reserves to meet the needs of the large energy-intensive industries, such as steel, chemicals, and fertilizers. These industries have often been the foundation of economic growth. Natural gas is also rapidly penetrating the electric power generation sectors. The consumption of gas by small- and medium-scale industries, on the other hand, is largely limited to areas with established city distribution systems. In the absence of significant space heating needs, the growth of residential and commercial usage of natural gas has been limited.

The domestic gas industry in developing countries will be examined in this paper with emphasis on industrial natural gas applications, the markets for which are relatively large compared to those of the commercial and residential sectors.

INDUSTRIAL UTILIZATION OF NATURAL GAS -- THE TECHNOLOGIES

Natural gas can be used in a wide variety of industrial applications. In general, gas uses in industry can be classified under two broad categories: raw material and industrial fuel. Natural gas, which contains methane as the dominant component, is used as a chemical feedstock instead of naphtha or fuel oil for the manufacture of nitrogen fertilizers and methanol. The heavier components (ethane, propane, butane) can be used as feedstocks for steam crackers to obtain a range of intermediates. Natural gas can also be used as a fuel to displace oil or coal in both direct and indirect heating applications. The industries that use natural gas as fuel or raw material manufacture a wide range of products. Electric power production by utilities and independent producers is also a viable gas use.

Power Generation[1-3]

Electric generating plants have often been the first customers served with natural gas in many developing nations, especially those with little need for space heating. Several modes of gas use in existing plants are possible.

*The production figures are higher than the consumption figures in Table 5 because the latter are essentially all domestic natural gas usage, while the production data include domestic usage as well as exports.

Table 5. COMPARISON OF NATURAL GAS RESERVES, PRODUCTION, AND CONSUMPTION FOR DEVELOPING COUNTRIES AND WORLD[a]

	Reserves	Production	Consumption
All Developing Countries, 10^9 CF	1,542,359	10,787	10,063
Percent of World Total	36.7	14.3	13.7
Ten Developing Countries,[b] 10^9 CF	1,066,681	7,805	6,230
Percent of World Total	25.3	10.3	8.5
Percent of All Developing Countries	57.9	72.4	61.9

[a]Adapted from Table 4.

[b]Algeria, Argentina, China, Hungary, Indonesia, Iran, Mexico, Pakistan, Poland, and Venezuela. Each of these countries consumed more than 420 x 10^9 CF in 1989.

- Conversion of existing boilers in steam plants to natural gas.
- Conversion of existing turbines or engines in "internal combustion" plants to gas.
- Addition of new equipment designed for gas use in parallel to, or in tandem with, existing equipment such as boilers, turbines, or engines.
- Conversion of existing equipment to dual-fuel capability (for example, boilers, turbines, or engines).
- Co-firing with existing fuel to reduce emissions from coal or oil alone.
- Usage of natural gas after-burners to clean stack gases.

Most gas-fueled power-generating systems now in the design or construction stage use modern gas turbines that offer higher efficiencies, low emissions, and established reliability. Combined-cycle and steam-injected gas turbine systems are accepted worldwide for utility and industrial applications. Efficiencies for combined-cycle plants have increased steadily over the last few decades. Modern systems currently operate at over 50 percent efficiencies for power-only plants.

Gas-fired cogeneration is an attractive option in many industrial facilities where electricity, process heat, and steam are needed. The principal systems used for the simultaneous production of electricity and process steam are often based on the use of combustion turbines for oil or gas fuels with waste heat and possibly auxiliary fired boilers if needed to meet steam load.. In the case of gas, cogeneration involves the generation of electricity using a gas engine or gas turbine and the recovery and utilization of waste heat. Because natural gas requires minimal auxiliary facilities for fuel handling, storage, pumping, and environmental control, it is especially suitable for cogeneration in industrial plants. Gas turbines are significantly less expensive than coal- or oil-fired boilers with steam turbines and operate with the same or higher efficiency, greater dependability, and less maintenance than oil-fired turbines. Their rapid start-up capability and light weight also give gas turbines additional advantages over heavier boilers or steam plants. As a result, gas-fired cogeneration has become quite common in well developed gas markets.

Chemicals and Polymers[2,4,5]

Natural gas is an established feedstock for the manufacture of several primary chemicals -- carbon blacks, hydrogen and synthesis gases (mixtures of hydrogen and carbon monoxide), methanol, and nitrogen fertilizers (ammonia and urea). High-grade carbon blacks are manufactured in a cyclic process by thermally cracking natural gas. Hydrogen and synthesis gases are made by partial oxidation or steam reforming of natural gas. In the United States, over 90 percent of the intentionally produced hydrogen from natural gas is manufactured by catalytic steam reforming rather than partial oxidation, which is usually preferred for heavier hydrocarbon feedstocks. Methanol is produced by reduction of the carbon monoxide in synthesis gas using "low-pressure" processes, which are usually designed around copper-based catalysts. For ammonia production, synthesis gas is processed to ultimately form a purified 3:1 hydrogen-nitrogen mixture for catalytic conversion to ammonia at elevated pressures and temperatures. Urea is manufactured by reaction of ammonia and carbon dioxide at high pressure and temperature to form the intermediate ammonium carbamate, which is then dehydrated to form urea.

Another major source of chemicals from natural gas is the natural gas liquids separated from associated and non-associated natural gas in gas processing plants. Steam cracking of the resulting C_2^+ hydrocarbons ethane, propane, and the butanes yields the olefins ethylene, propylene, and butylenes, and other products. The olefins are valuable feedstocks for the manufacture of polymers such as polyethylene and polypropylene. Natural gas liquids are particularly suited for the production of ethylene and propylene because olefin yields and selectivities from the steam cracking of ethane and propane are considerably higher than the corresponding yields and selectivities from the steam cracking of alternative feedstocks such as naphthas and gas oils. Also, the economics strongly favor the use of natural gas liquids.

Natural gas is also used in the plastic products industry to supply platen heating for thermosetting operations. Although the plastics processing industry is dominated by electrically heated equipment, gas-fired systems offer an attractive alternative to existing equipment. Benefits include precise heating levels, closer temperature control, relatively low installation costs, low operating and maintenance costs, improved operating safety, and process flexibility. Installation costs, which include the heater, burner, control panel, expansion tank, deaerator, and main circulating pump in centralized thermal fluid systems, range from $22,000 to $55,000 for 1.0 to 6.0-MBtu/h systems.

Steel[6]

The steel industry uses natural gas in several operations including scrap preheating, ladle heating, and blast furnace injection.

The benefits of using natural gas for scrap preheating are well known -- less energy consumption, longer electrode life, quicker melt cycles, elimination of fume problems, and removal of moisture in scrap, the cause of some furnace explosions, -- are some of the benefits.

Currently, there is a strong movement in the iron and steel industry toward greater use of the electric arc furnace-steel making process. Although the process can achieve a high overall thermal efficiency, it can also be time-consuming, taking about 1 to 2½ hours to melt enough charges to reach the furnace's liquid metal capacity. Attempts have been made to speed up the process and to increase productivity by providing an auxiliary heat source. The use of oxygen-natural gas burners, which provide temperatures of about 2,700°C, as compared to temperatures of about 2,200°C from conventional air-natural gas burners, has been found to provide quicker melt cycles and longer furnace electrode and refractory life.

Ladles are used to carry molten metals from the melting furnace to where the metal is cast. The ladles must be preheated to minimize thermal shock to the refractory brick lining. Gas-fired preheating systems that utilize recuperation, combustion controls, and cover seals to achieve thermal efficiencies in the 50 percent range and exhaust gas at temperatures of about 200°C, as compared to exhaust gas at about 980°C from older preheaters, are commercially available. They are suitable for a wide range of ladles sizes from 1 to 400 tons.

Natural gas is one of several hydrocarbon fuels that can be injected into the blast furnace to replace metallurgical coke. However, coke is required in blast furnace iron manufacture to support the descending iron ore burden and to supply the chemical reductant and heat requirement. Natural gas can replace coke to some extent for heat and chemical reduction, and currently, studies are in progress to quantify some of the intangible benefits of natural gas injection in blast furnaces.

Forging, Foundries, and Heat Treating[7]

Forging is the process of forming metal to a desired shape by impact or pressure. The resulting part has higher strength, impact, and fatigue resistance than either the solidified structure of a casting or a machined part. The major gas-consuming processes are in the billet-heating, die-heating, and heat-treating steps. An integrated forge shop with fuel-fired forge furnaces is estimated to consume approximately 18,000 Btu per pound of material, but energy conservation efforts over the past decade have reduced energy consumption in the forging industry significantly. Forging furnaces heat the metal stock to about 1,200-1,300°C and natural gas is the preferred fuel. Propane and fuel oil are also used. Major advancements have been made over the last several years in heat recovery through the development of improved recuperators, controls, and forging furnace operation and design.

Foundries produce complex metal shapes from melted metal stock by pouring the liquid into a mold to form the desired shape. This process is called metal casting and is important in the production of industrial equipment, construction materials, and consumer durables from all types of metals. The primary markets for ferrous castings are motor vehicles, construction equipment, farm equipment, oil field goods, and machine tools.

Air pollution abatement has been an ongoing problem, particularly for coke-fired cupolas, and provides increased opportunity for combined gas and coke-fired, or cokeless cupolas. Natural gas usage is important in several process steps in the foundry industry such as for gas-fired cupolas, scrap preheating, improved ladle heating, and sand reclamation. The latter application represents a relatively new use for natural gas in the foundry industry and involves the thermal reclamation of sand commonly used for making molds and cores.

The properties of ferrous materials are determined by the carbon and alloy content of the material and by its microstructure. For a given composition, the material's properties can be controlled by both mechanical and heat treatment. Heat treatment affects the microstructure solely by the application of heat in a family of processes such as annealing, in the 700-900°C range, and hardening, in the 150-700°C range. Natural gas is often used in these processes and also for the generation of controlled atmospheres for use in heat treatment of ferrous materials.

Aluminum[8]

The process of converting bauxite into finished aluminum can be described in terms of several major natural gas-consuming activities -- conversion of bauxite to aluminum oxide, reduction of aluminum oxide to molten aluminum, casting molten aluminum into intermediate shapes, continuous casting of molten aluminum, remelting or reheating of intermediate shapes, heat treatment, and melting of recycled aluminum. A wide range of gas-fired equipment is used for drying, melting, and heating applications in the industry, such as kilns, anode-baking ovens, melting furnaces, and heating furnaces. Much of this technology is not unique to the aluminum industry and is shared with other industries utilizing similar processes. The energy usage of the aluminum industry ranges from about 85,900 Btu per pound, using the best available current technology, to about 94,400 Btu per pound. In the U.S.A., natural gas accounted for about 37 percent (142×10^{12} Btu) of the total energy used by the aluminum industry in 1983.

Glass[9]

The manufacture of glass generally consists of a sequence of four basic steps -- crushing, mixing, and conveying of raw materials by batch; melting the raw materials to form molten glass; forming intermediate or final solid shapes; and post-forming processing. Some of the factors that affect the choice of energy for a particular glass manufacturing process are glass quality, productivity, process controllability, initial equipment costs, and emissions. Generally, gas equipment has a higher capital cost than its electric counterpart, but significantly lower operating costs due to the difference between gas and electricity prices. The cost of emission-control facilities is a major consideration for the initial cost of gas-fired equipment. Electric equipment usually requires significant associated power supply expenditures. But energy use in the glass industry is dominated by natural gas, which accounted for approximately 83 percent (192×10^{9} Btu) of the total for the U.S. glass industry in 1986; electricity and oil accounted for about 15 percent and 2 percent, respectively.

Solids Drying[10,11]

The drying of solids is one of the largest energy-consuming unit operations in industry and occurs during production of a large number of products. As shown in Table 6, natural gas ranked second in 1985 in the U.S.A. as an energy source for drying industrial products behind steam, which is the most common energy source for drying applications and which accounted for over 61 percent of the total energy consumed. Natural gas accounted for about 26 percent (243×10^{12} Btu). The major users of natural gas for industrial drying are the agricultural, minerals, textiles, paper, and chemical industries.

In the agricultural industry, many crops are dried in order to extend the storage life of the product. Among these crops are corn, rice, tobacco, peanuts, and soybeans. Dried products in the mining industry include copper. bauxite, coal, sand, clays, gypsum, talc, and diatomite. Food products are typically dried to extend shelf life or storage time and to improve handling and processing of the product. Textiles are dried several times during processing, and almost all wood products are dried at some point during

Table 6. U.S. DRYING ENERGY USE BY INDUSTRY, 1985[a]

Industry	Throughput, 10^6 lb	Energy Intensity, Btu/lb	Drying Energy, 10^{12} Btu						
			Gas	Coal	Oil	Steam	Electric	Biomass	Total
Agriculture	263,776	245	22.7	0	38.6	3.42	0	0	64.7
Paper	156,302	2,401	40.4	0	0	334	0.592	0	375
Lumber	125,934	1,108	1.06	0	0	105	0	33.8	140
Chemicals	118,088	871	20.1	0	12.1	70.7	0	0	103
Minerals	107,906	578	60.2	1.18	0.995	0	0	0	62.4
Coal	106,036	299	0	31.5	0	0	0	0	31.5
Textiles	70,668	1,321	62.2	0	0	31.2	0	0	93.4
Food	55,552	838	16.0	0	0	30.5	0.013	0	46.6
Stone, Clay, Glass	29,524	509	13.5	0	0.785	0.719	0	0	15.0
Metals	9,749	465	4.54	0	0	0	0	0	4.54
Metal Ores	3,923	651	2.56	0	0	0	0	0	2.56
Total	1,047,462		243	32.7	52.5	576	0.605	33.8	939

[a]Adapted from Table 1 in Ref. 11.

processing. All paper products are dried at least once during processing, while in the stone, clay, and glass industries, dried products include wall and floor tiles, plumbing fixtures, and ceramic casting slips, as well as fiberglass, dry processed cement, and mineral wool. In the metals industries, both sand casting molds and cores in ferrous and non-ferrous foundries are dried before casting.

As an example of how natural gas is used for drying, a few details are presented here on the pulp and paper industry. The manufacture of paper involves several unit operations: pulping, cleaning, screening, deinking in the case of recycling, and bleaching. Water is used as a liquid vehicle to transport the cellulosic fibers to the paper-producing machine where the fibers are distributed to form sheets. Drying is a major operation and is accomplished by several techniques such as infrared heating, drum drying, and convection drying. Market pulp, paper, and paperboard are all dried before shipping. Steam-heated can driers are used for sheet and board products; press and conveyor driers are used for market pulp and thicker paperboards; air-impingement drying is used for tissues; and infrared driers are used for coated papers. Steam is the dominant heat source in paper drying because ample supplies of black liquor and waste wood are available as fuels. Other fuels compete in drying tissue papers and coated papers where non-contact infrared heat is used to avoid discoloring the coated surface. For every pound of water evaporated from paper sheets, whether it be basic pulp, primary drying, or coating drying, about 1,000 Btu must be transferred to liquid water to form water vapor for subsequent exhaust in the air stream. As a result, paper drying is the largest drying industry in the U.S.A.; it consumed over 375×10^{12} Btu of energy in 1985. Of this amount, about 40×10^{12} Btu, or about 11 percent of the total, was achieved with natural gas.

INDUSTRIAL MARKETS FOR NATURAL GAS IN U.S.A.

Table 7 illustrates energy usage by U.S. industry in 1985.[12] Of a total of 22.5 quad, natural gas contributed about 31 percent. The largest user of natural gas was the chemical industry. It consumed gas as a source of heat and power in manufacturing processes and as a feedstock for the processes themselves. Interestingly, the next largest use of natural gas was for the production of petroleum and coal followed by the primary metals industry.

Further details on U.S. industrial energy consumption in 1985 by end-use are shown in Table 8.[12] The largest end-use of natural gas by U.S. industry is for process heating followed by boiler steam. It is also evident from Tables 6 and 7 that natural gas provided more energy for industrial manufacturing processes than any of the other energy resources. Figures 1 and 2 illustrate how industrial energy use varied in the U.S.A. by energy resource from 1960 to 1987.[12] It is evident that natural gas maintained its share over this period.

In many manufacturing applications, natural gas is often the fuel of choice because it simplifies the operation, increases fuel utilization efficiency, and reduces operating and manufacturing costs. In addition, the characteristics of natural gas combustion are preferred because of the beneficial environmental impact on emissions and pollutants, and waste

Table 7. U.S. INDUSTRIAL ENERGY USE BY INDUSTRY, 1985[a]

	Energy Source, Quad						
Industry/Use	Gas	Coal/Coke	Petroleum Products	Process Byproducts	Fuel Oil	Net Electric	Total
Feedstock	0.718	0.979	3.181	--	--	--	4.878
Manufacturing Heating and Power							
Chemicals	1.181	0.336	0.398	--	0.100	0.445	2.460
Petroleum & Coal Production	0.691	0.007	1.473	--	0.135	0.120	2.426
Primary Metals	0.644	0.150	0.111	0.409	0.053	0.459	1.826
Food	0.459	0.132	--	0.133	0.065	0.166	0.954
Stone, Clay, Glass	0.397	0.349	0.032	--	0.033	0.116	0.928
Pulp and Paper	0.380	0.323	--	1.303	0.167	0.184	2.356
Fabricated Metals	0.172	0.087	0.008	--	0.017	0.091	0.296
Transportation Equipment	0.121	0.044	0.017	--	0.026	0.115	0.322
Machinery	0.114	0.031	0.005	--	0.015	0.114	0.278
Rubber and Plastics	0.102	0.081	0.005	--	0.015	0.091	0.221
Electrical Equipment	0.091	0.009	--	0.003	0.010	0.110	0.224
Textiles	0.091	0.038	--	0.010	0.021	0.088	0.248
Printing & Publishing	0.041	0.003	10	0.0004	0.002	0.053	0.099
Lumber & Wood	0.031	0.015	--	0.224	0.023	0.055	0.349
Instruments	0.024	0.002	--	0.017	0.008	0.029	0.080
Furniture and Fixtures	0.020	0.002	--	0.009	0.003	0.015	0.049
Misc. Manufacturing	0.015	0.001	--	0.0007	0.003	0.011	0.031
Apparel	0.012	0.001	--	0.0004	0.003	0.015	0.033
Leather Goods	0.005	0.0009	--	0.0004	0.003	0.004	0.013
Tobacco	0.003	0.009	--	0.0001	0.002	0.005	0.020
Subtotal	4.592	1.470	2.049	2.110	0.705	2.287	13.212
Non-Manufacturing	1.776	0.308	0.532	--	1.236	0.560	4.411
Total	7.087	2.757	5.761	2.110	1.941	2.846	22.502

[a]Source: Adapted from Table 1 of Ref. 12. Summations may not equal arithmetic sums because of rounding.
1.00 quad = 10^{15} Btu.

Table 8. U.S. INDUSTRIAL ENERGY USE BY END-USE, 1985[a]

End-Use	Energy Source, Quad						
	Gas	Coal/Coke	Petroleum Products	Process Byproducts	Fuel Oil	Electric	Total
Feedstock	0.718	0.979	3.181	--	--	--	4.879
Manufacturing Heat and Power							
Boiler Steam	1.7901	0.266	0.826	1.007	0.350	--	4.239
Cogenerated Steam	0.508	0.641	0.195	0.742	0.116	--	2.202
Cogenerated Power	0.277	0.119	0.043	0.138	0.032	--	0.609
Process Heating	2.017	0.444	0.985	0.223	0.207	0.162	4.038
Shaft Power	--	--	--	--	--	1.753	1.753
Electro Processes	--	--	--	--	---	0.430	0.430
Lights & Other	--	--	--	--	--	0.233	0.233
Subtotal	4.592	1.470	2.049	2.110	0.705	2.578	13.504
Non-Manufacturing							
Lease & Plant	1.085	--	--	--	--	--	1.085
Mining	0.509	0.308	0.040	--	0.272	0.319	1.448
Agriculture & Forestry	0.182	--	0.325	--	0.337	0.181	1.025
Construction	--	--	0.166	--	0.627	0.067	0.860
	1.776	0.308	0.532	0.0	1.236	0.567	4.418
	7.087	2.757	5.761	2.110	1.941	3.145	22.801

[a]Adapted from Table F-3 of Ref. 12. Summations may not equal arithmetic sums because of rounding. 1.00 quad = 10^{15} Btu.

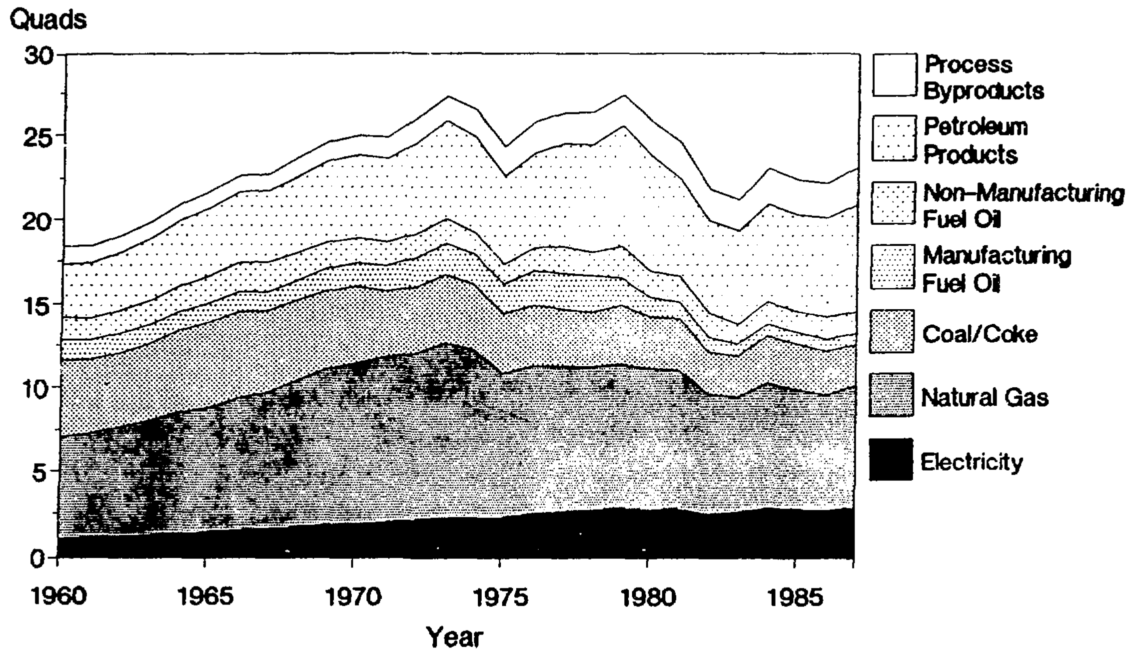

Figure 1. U.S. INDUSTRIAL ENERGY CONSUMPTION 1960-1987

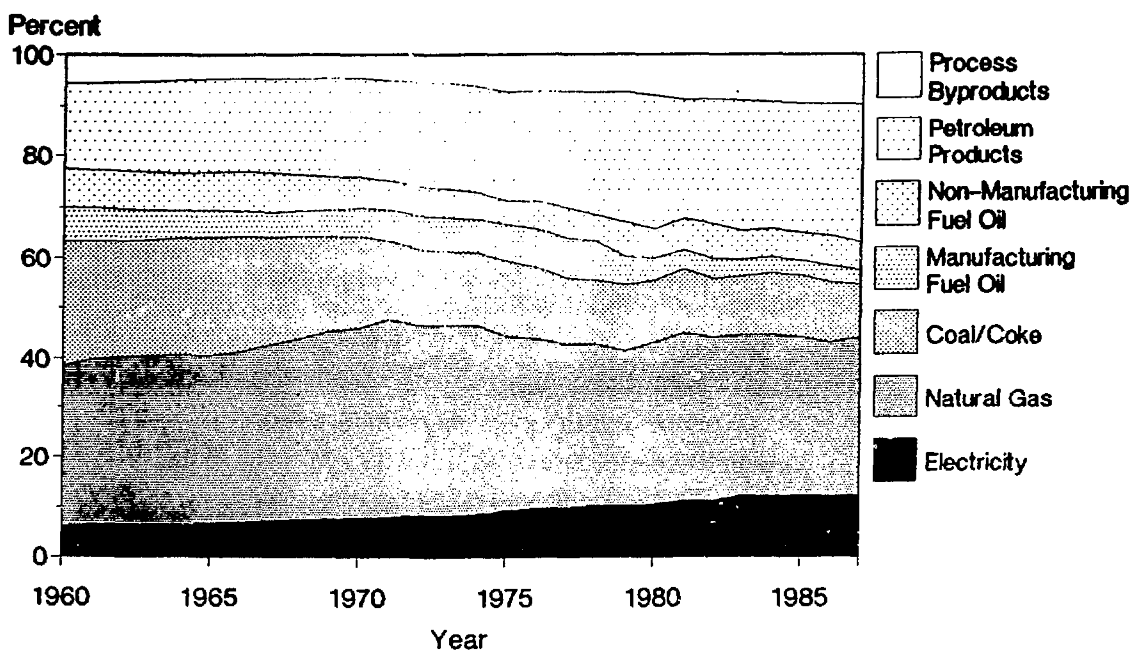

Figure 2. U.S. INDUSTRIAL ENERGY SHARES, 1960-1987

Source: Figures 1 and 2 of Ref. 12.

generation and disposal. Also, the use of natural gas in a manufacturing process often imparts improved properties to the final product.

INDUSTRIAL MARKETS FOR NATURAL GAS IN DEVELOPING COUNTRIES

The largest domestic uses of natural gas in most developing countries are the industrial and electric power generation markets as illustrated by the data compiled in Table 9.[13,14] Australia, Japan, and the U.S.A. are included as examples of industrialized countries for comparison. It is apparent from the data in Table 9 that, with the exception of Pakistan, natural gas consumption in the residential and commercial sectors is small in developing countries.

Using Indonesia as an example of a developing country that is engaged in expanding its domestic natural gas markets, non-industrial use of natural gas in urban areas in 1987 was only about 5×10^6 CF/d.[13] Jakarta, the capital of Indonesia, and other Indonesian cities would be expected to offer large ready-made commercial and residential markets for natural gas in addition to the growing industrial markets. The largest domestic natural gas markets in Indonesia are currently made up of the steel, cement, and fertilizer industries, in addition to petroleum refinery fuel usage. It should be emphasized, however, that currently, Indonesia is the world's largest exporter of LNG, which in 1987 accounted for about 80 percent of Indonesia's total natural gas market.

Industrial natural gas usage in developing regions of the world has been the second largest market as shown in Table 10; electric power production is the largest.[15,16] Using Indonesia again as an example of a developing country, gas-fueled systems have exhibited a high growth rate. The electric power sector is expected to undergo increases in installed capacity of more than 500 percent in the next decade, while a reduction of oil-fired capacity is expected to occur over the same period.[13] It is noteworthy that even though natural gas-fired, installed, electric generating capacity is projected to be less than that of oil-fired installed capacity in 1999, the power output is greater for gas-fired systems. This is undoubtedly due to the higher efficiencies of the new combined-cycle, gas turbine power plants as compared to those of conventional steam plants.

Fuel Substitution

The penetration of natural gas in the industrial fuel markets of developing countries is considered attractive for several reasons. Natural gas carries a high value when substituting for tradeable fuels. In addition, natural gas users can also benefit from lower operating and maintenance costs of equipment, particularly when compared to those of coal, and from the fact that gas firing eliminates the need to carry fuel inventories. Industrial surveys carried out in a number of developing countries indicate that if gas is available in sufficient quantities, it will be the fuel of choice when all fuels are priced to reflect their opportunity costs.[1] Natural gas can, therefore, capture a significant share of the industrial fuel market in many developing countries if the required infrastructure is in place.

Table 9. RECENT NATURAL GAS CONSUMPTION BY SECTOR FOR SELECTED COUNTRIES
(Percent)

Country	Residential	Commercial	Industrial	Electric Power	Others
Bangladesh	6.3	2.4	54.1	37.3	--
Burma	--	--	76.3	23.7	--
China	7.5	0.5	88.0	3.8	0.1
India	0.3	--	77.9	20.6	1.2
Indonesia	0.7	9.0	88.1	2.1	0.1
Malaysia	--	--	78.4	20.2	1.4
Pakistan	13.3	3.2	53.5	30.0	--
Thailand	--	--	9.2	90.8	--
Australia	13.3	5.2	0.2	21.2	0.1
Japan	19.9	5.4	9.6	65.0	0.1
U.S.A.	25.4	14.5	36.3	14.7	9.1

Source: Refs. 13 and 14 for Indonesia; Ref. 14 for the other developing countries, Australia, and Japan; IGT archives for U.S.A. Gas exports are excluded.

Table 10. SECTORAL CONSUMPTION OF NATURAL GAS BY REGIONS OF WORLD[a]
(Percent)

Region	Residential/ Commercial	Industrial	Electric Power	Others[b]
Africa	3.5	12.5	80.5	3.5
America, South	9.5	36.5	47.5	6.5
Asia	8.5	31.5	38.5	21.5
Middle East	6.0	25.0	60.0	9.0
World	26.0	28.0	40.0	6.0

[a]Adapted from Table III.3 of Ref. 16.

[b]Primarily as raw material.

Industrial boilers for steam generation make up the largest share of fuel-consuming equipment in industry, and represent the market with the highest potential for significant gas penetration. The ready availability and flexibility of oil supplies at comparatively low prices in the two decades prior to the 1970s effectively made industrial energy equipment in most developing countries heavily dependent on oil. Despite the sharp rise in the price of oil since then, the long life expectancy of boiler equipment (30-40 years) has maintained heavy oil as the dominant fuel for industrial boilers in most developing countries. In the absence of the flexibility of an industrial grid, the possibilities for fuel substitution by simply altering the fuel mix for existing equipment has been limited to dual or multi-fuel burners.

For a large proportion of boiler fuel uses, the energy system selected is only fuel dependent up to and including the boiler. Thereafter, the distribution of steam and hot water is common to oil, gas, coal or any other heat source. Thus, industry's capital commitment to a particular fuel is actually confined to investments in the boiler stock and the fuel handling system. Gas may be substituted for oil in existing or new boilers with minimal cost, and environmental pollution problems are virtually eliminated. Gas-fired steam boilers are generally simpler to operate and efficiency is higher when compared to boilers fired with oil or coal. The change in fuels to natural gas generally results in efficiency increases from 3 to 5 percent, greater energy savings through reduction of scattered heat loss, longer boiler life, ease of handling and maintenance of equipment, and reduction of emissions.

Chemical Feedstock

The use of natural gas as chemical feedstock in ammonia, methanol, and petrochemical production has increased rapidly in Asia, Africa and the Middle East, while it has remained fairly stable in Latin America over the past fifteen years. The consumption of natural gas for chemical production in Africa has risen from less than 66,000 BOE in 1975 to nearly 30 million BOE in 1988. Much of this increase is the result of investments in gas-based chemical facilities undertaken in Libya since 1978. Libya currently accounts for about 67 percent of gas-based chemical production in Africa. The chemical industries in Algeria, Egypt, and, to a lesser extent, Tunisia, also use gas as a feedstock.

Large-scale use of natural gas as chemical feedstock has been ongoing in Latin America since the early 1970s. After rapid growth in the late 1970s, the use of natural gas as chemical feedstock has grown in line with the increase in overall gas consumption in the 1980s. Feedstock uses currently represent about 17 percent of total gas use. Once again, one country, Mexico, accounts for a predominant share (about 62 percent) of the regional chemical feedstock applications of natural gas. In Mexico, the chemical industry represents the second largest consumer of gas after the energy sector. Starting at a much smaller base, the chemical industry is the largest consumer of gas in Brazil. Gas is also used as chemical feedstock in Venezuela, Trinidad and Tobago, Colombia, and more recently, Chile.

The use of natural gas as chemical feedstock in Asia has increased rapidly in the past fifteen years to around 79 million BOE in 1986. For the region as a whole, the chemical industry represents the largest consumer of natural gas and accounts for over 30 percent of regional natural gas consumption. It is the largest consumer of gas in China and India, and the second largest consumer in Bangladesh, Indonesia, and Malaysia. In Bangladesh, natural gas is used primarily for power generation and fertilizer production. In Indonesia and Malaysia, gas use in the fertilizer and petrochemical industries is second only to gas use for LNG production. Gas use for chemical production is also significant in Pakistan, but trails behind power generation and fuel applications.

Chemical feedstock applications of natural gas in the Middle East have been limited in both absolute and relative terms. Gas consumption in chemical plants amounted to around 42 million BOE in 1986, or about 10 percent of total gas consumption. The largest user of gas in the region is the energy sector itself, followed by power generation. The use of gas for chemical production is virtually non-existent in Iran, the largest gas consumer in the region.

Future Growth

As for the future growth of domestic natural gas consumption in the industrial markets of developing countries, a reasonably good projection can be made by examination of the data in Table 11. Current natural gas consumption is compared with total domestic energy consumption for the ten major gas-consuming, developing countries, a few other developing countries, and the U.S.A. Reserves-to-production ratios and per-capita-energy consumption are also included in these data. With the exception of Brazil, China, and India, it is apparent that natural gas supplies a large proportion of total domestic energy consumption. It is also evident that the reserves-to-production ratios for natural gas in the developing countries are much higher than the corresponding ratio for the United States. Thus, proved reserves are available for further development and distribution in the developing countries listed in Table 11, and substantial expansion of domestic gas markets is possible.

The development of industrial gas markets in Malaysia is exemplary of the future role of natural gas in developing countries. New projects scheduled for completion in the next few years include an ethylene complex for the manufacture of low- and high-density polyethylene (7.3×10^9 CF/yr), and plants for the manufacture of caprolactam (8.8×10^9 CF/yr), methyl-t-butyl ether (3.6×10^9 CF/yr), and middle distillates (36.5×10^9 CF/yr).[17] In addition, the installation of the Peninsular natural gas pipeline, to be discussed later in more detail, will facilitate the conversion of oil-fired power plants in Malaysia to natural gas. It is expected that the majority of the fuel oil users in the manufacturing industry will convert to natural gas also.

ISSUES AFFECTING INDUSTRIAL GAS MARKETS IN DEVELOPING COUNTRIES

The domestic gas industry, and industrial gas markets in particular, have exhibited relatively slow growth in most developing countries that are fortunate enough to have sufficient natural gas reserves to meet domestic energy needs. It is only possible to outline the major issues that affect these markets and the causes of this apparent anomaly in this paper because of the complex interactions that continually occur during the flow of products, services, and energy in the economy of a developing country.

Table 11. COMPARISON OF NATURAL GAS, TOTAL ENERGY, AND PER-CAPITA ENERGY CONSUMPTION, AND NATURAL GAS RESERVE-TO-PRODUCTION RATIOS FOR SELECTED COUNTRIES[a]

Country	Natural Gas, quad	Total Energy, quad	Natural Gas % of Total	Natural Gas R/P[d]	BOE/Capita[e]
10 Developing Countries[b]					
Algeria	0.70	1.64	42.7	72	4.48
Argentina	0.81	1.71	47.3	33	9.28
China	0.52	24.79	2.1	68	3.88
Hungary	0.42	1.07	39.3	--	17.6
Indonesia	0.49	1.38	35.5	66	1.31
Iran	0.73	2.27	32.2	703	7.29
Mexico	0.96	4.07	23.6	55	8.09
Pakistan	0.46	0.88	52.2	43	1.28
Poland	0.50	4.81	10.4	--	21.7
Venezuela	0.63	1.51	41.7	123	13.5
Other Developing Countries[c]					
Brazil	0.11	3.27	3.4	36	3.82
Egypt	0.25	1.06	23.6	52	3.58
India	0.32	7.14	4.5	57	1.47
Malaysia	0.30	0.67	44.8	100	6.60
Nigeria	0.14	0.56	25.0	652	0.92
Thailand	0.19	0.97	19.6	28	3.05
U.S.A.	18.8	81.3	23.1	9	48.5

[a]Source: IGT's Energy Statistics and gasLine®. 1.00 quad = 10^{15} Btu.

[b]Each of these countries consumed more than 420 x 10^9 CF of natural gas in 1989. The range was 421 x 10^9 CF (Hungary) to 963 x 10^9 CF (Mexico).

[c]The range of natural gas consumption in 1989 for these countries was 114 x 10^9 CF (Brazil) to 318 x 10^9 CF (India).

[d]Proved reserves divided by total production.

[e]BOE = Barrels of oil equivalent. 1.00 BOE = 5.8 x 10^6 Btu.

Infrastructure and Deliverability

Historically, exploration for fossil fuel has focused largely on the search for oil; natural gas discoveries were often considered to have little or no value. Associated gas discoveries were often given a negative value because they added to the cost of oil production. The result was early development and commercial utilization of petroleum deposits. Natural gas development for domestic use was given a low priority and attainment of its full potential was delayed.

Another important factor that hindered development of domestic natural gas markets is the large capital investment needed to install pipelines to transport and deliver sustainable supplies of natural gas to end users. Before establishment of an adequate infrastructure to assure gas deliverability, it was simply more economic and less risky to transport readily storable solid and liquid fuels to domestic markets. This approach avoided the inevitable decision that had to be made to invest the needed capital.

In the United States, for example, the "cost of service," which includes capital and operating costs, of a modern, large-diameter, high-pressure gas pipeline is about $0.20 per million Btu ($10^3$ CF) of annual natural gas capacity per 100 miles of pipeline.[18] An oil pipeline has a lower cost of service per million Btu delivered than a natural gas pipeline. Currently, the U.S. gas grid consists of about 91,000 miles of field and gathering pipeline, and 280,000 miles of transmission pipeline.[19] In today's dollars, this represents over $700 billion in capital investment.[20,21] It is therefore mandatory that the decision to install a natural gas pipeline not be made quickly. Several person-years of effort must be devoted to detailed design, equipment, and technology evaluations; to assessment of long-term markets and deliverability requirements; to economic analyses; to capital needs and resources; and to financing arrangements before a firm decision is made to install a large natural gas supply system. This is especially important for countries in which the gas fields and gas markets are far apart. It is obvious that joint arrangements with organizations that have established track records in the design and construction of natural gas transmission and distribution systems are in order to minimize risks and costs.

In a few countries that targeted LNG production for export as the prime market for natural gas, domestic gas markets have sometimes been given a low priority. Existing gas supply systems for domestic markets then received less attention and began to deteriorate to the point in some cases where they became unsafe to use. Although the economic returns from LNG exports were attractive, the long-term adverse effects on domestic gas supply systems reduced their deliverability or postponed construction of new systems. This precluded realization of the benefits of natural gas consumption in all sectors of the domestic economy, particularly in domestic industrial applications.

As a result of the slow pace of installing the infrastructure needed to supply existing and potential gas users in developing countries, and the dependence of several of these countries on oil exports as economic pump-primers, the reserves-to-production ratios for natural gas are relatively high compared to the corresponding ratios for oil. Indeed, a few countries that have been in the oil-export market for many years are projected to become oil-importing countries at the turn of the century. Some developing countries are now in a position of having to rely on natural gas to displace oil for both conservation purposes and export because oil exports have a more favorable economic impact on foreign exchange and the balance of payments than natural gas.

The fact remains, however, that without a suitable infrastructure in place, utilization of natural gas in all domestic markets is very limited.

Even after installation of a domestic gas delivery system, the lack of a work force trained in the technologies of natural gas transmission, distribution, and utilization can result in serious problems. It is essential that knowledgable management, operating, and maintenance personnel be available to ensure continuity of gas supply on demand in a safe and efficient manner. This requires the careful planning of training programs and their implementation for almost all system personnel.

Government Policy and Regulation

Basic Regulation. Government regulation can be a very complex undertaking and can have a very large impact on development of a domestic gas industry. In its simplest terms, the natural gas industry in a given country is generally regulated by a body that prescribes and enforces safety measures, oversees the quality and efficiency of service, and monitors the pricing structure. The first objective of regulation is safety and safe working practices, which should ensure that only trained and competent persons are involved with the design, maintenance and operation of supply and distribution systems. Legislation or imposed regulations may be used to delineate the broad requirements for safety related to meters, compressors, controls, piping, and gas-fueled equipment and appliances. These rules may be supplemented by detailed instructions in the form of Codes of Practice. In developing countries, past experience suggests that it is more efficient for an operating organization to develop its own codes instead of having them developed by a regulatory body.

The next objective of regulation is to ensure a reliable and cost-effective gas supply system. For this purpose, the regulatory body may authorize an operating organization to supply gas to designated areas. In turn, the organization might be required to agree to various conditions and obligations, such as developing and maintaining an efficient, economic supply system, and to meet any reasonable request for gas supplies.

The regulatory body may also be responsible for monitoring the price of gas paid to producers and the price charged to consumers. In the event of dispute between contracting parties, the regulatory body may act as a mediating agency.

Industrialized Countries. Industrialized countries have usually relied on a domestic energy strategy that utilizes all economically available energy resources. Whenever possible, markets are allowed to determine prices, quantities, and technology choices. In specific instances where markets cannot or do not function in an efficient manner, government action and regulation are applied to try to remove or overcome barriers to efficient market operation. The gas industry of the United States is perhaps the best example where regulation was initially designed to protect the consumer, but has frequently had the opposite effect. This resulted in proposed elimination of all gas price controls at the wellhead by January 1993, and a National Energy Strategy that is stated to remove regulation, except where necessary to protect consumers, while enabling all segments of the industry to expand.[22] If fully implemented, the National Energy Strategy is expected to increase annual domestic U.S. consumption of natural gas by about 10^{12} CF, or by about 5 percent, over that which would have occurred in the year 2000 under pre-Strategy policies.

Specifically, the National Energy Strategy is expected to:

- Expedite gas pipeline construction.
- Streamline implementation of the National Environmental Policy Act associated with natural gas pipeline construction.
- Deregulate pipeline sales rates.
- Improve access to natural gas pipeline transportation services.
- Eliminate the Department of Energy's import and export regulations.
- Encourage the use of natural gas as an alternative transportation fuel.

All of the above projections and expectations can best be described as typical of a large open government in action. If removal of most regulations and controls results in the expected benefits for natural gas producers, distributors, and users, the National Energy Strategy will have been well worth the time and effort needed for its formulation and implementation. This remains to be established, however, because of the differing positions of individual legislators and the interactions of the executive and legislative branches within the U.S. Government.

Developing Countries. Government policies in developing countries can also have a very large impact on domestic natural gas markets and on the gas industry as an entity. Such factors as competitive fuel price controls, tax incentives and disincentives, energy import and export policies, legislation and regulation, and mid- to long-term energy strategies and objectives, all play major roles in promoting or slowing the development of a domestic gas industry in a developing country. It is important to emphasize that a government's energy policies can often be mandatory and implemented as law. Such policies have resulted in rapid growth of domestic gas consumption in several developing countries, especially over the last 10 years. Much of this growth has had little or no relationship to the Law of Supply and Demand in an open economy.

In some developing countries with advanced hydrocarbon exploration programs, a single government-owned or private company may have the responsibility for all activities related to the exploration, production, and transmission of oil and gas. Such a company may also be responsible for negotiating contracts for sale of natural gas to bulk consumers, and the construction of the necessary supply infrastructure. With sufficient expansion in the size of reserves and markets, it may become necessary to create a single coordinating body to guide or oversee the expansion of the natural gas sector. This body is generally responsible for the long-term planning needed to provide the necessary infrastructure and to coordinate the multiple requirements of the producers, distributors, and consumers.

A few recent examples are cited here to illustrate the evolution of institutional arrangements in the gas sector of a few developing countries.

The Algerian Government has placed a high priority on the development of its gas reserves, mainly for sale as LNG and transmission under the Mediterranean Sea via submarine pipeline through Italy to Europe.[23] The entire system is government-owned and accounted for almost half of all investment at the time of installation. Algeria's LNG facilities are larger than those of Indonesia, but because of lack of foreign financial and technical involvement, which often helps to secure markets, the facilities operated at less than half capacity in the mid-1980s so that LNG exports were below those of Indonesia. As shown in Tables 4 and 11, domestic gas consumption in 1989 in Algeria was less than one-half of total gas production, but still accounted or over one-half of the total energy consumed in the country.

Some developing countries such as Trinidad and Tobago have opted to establish domestic gas-based industries (ammonia, methanol, urea, and steel) rather than to export gas.[23]

Malaysia's state-owned oil and gas production company, Petronas, is vested with the ownership and exclusive right to explore and produce the country's hydrocarbon reserves.[24,25] Upstream oil and gas operations are managed by joint ventures between Petronas and foreign oil companies. Presently, Petronas sells natural gas directly to its major customers in the peninsula. In the near future, when local gas distribution systems are implemented in 17 Malaysian locations, Petronas' role in direct sales will be limited to very large consumers. The responsibility for the distribution systems will be given to a private, joint venture in which Petronas will hold a limited share. Since 1984, Petronas has passed on all responsibility for gas processing and transmission to a wholly owned subsidiary and purchases gas from upstream producers.

Because of the oil crises that occurred in 1973 and 1979, the Malaysian Government promulgated a so-called "four-fuel" (oil, natural gas, coal, hydro) diversification policy, the goal of which was to reduce the country's dependence on imported fuel oil through utilization of indigenous energy resources. Although the oil price collapse in 1986 caused some resubstitution of oil for other fuels, natural gas consumption increased significantly, while oil consumption exhibited the opposite trend. The share of oil in the primary energy mix declined from 93.0 percent in 1971 to 79.0 percent in 1980 to 51.8 percent in 1988, while the corresponding figures for natural gas were 1.4 percent, 20.5 percent and 34.8 percent. As a result of the increase in production coupled with the orchestrated displacement of oil by natural gas, the net exports of oil and oil products increased from 94.3×10^6 bbl in 1985 to 128×10^6 bbl in 1988, representing an average annual increase of 10.8 percent. Malaysia has been a net exporter of oil since 1977.

Natural gas consumption grew at an annual rate of 53.1 percent from 1980 to 1988, when it was 14.5×10^6 BOE (84×10^9 CF). The percentages for power generation, industry, residential-commercial, and non-energy uses were 48.3 percent, 17.9 percent, 2.3 percent, and 30.8 percent, respectively.

A good example of Malaysia's effort to increase domestic gas consumption is the Peninsular Gas Utilization Project for power plant conversions from oil to gas. In this project, both associated and non-associated gas from offshore oil and gas fields is collected and sent via submarine pipelines to onshore processing plants at Kerteh on the East Coast to remove condensate and impurities. The gas is then transported in Stage I of the project via a 20-in. pipeline (3.7 miles) to a combined-cycle power plant and a 36-in. pipeline (25 miles) to a steel mill at a rate of 400 x 10^6 CF/d. In Stage II of the project scheduled for final completion in mid-1992, 750 x 10^6 CF/d will be transported in a 453-mile, 36-in. pipeline to power plants on the West and South Coasts as well as to Singapore. Successful completion of the first stage of the Peninsular Gas Utilization Project resulted in gas supplying 21 percent of the power generated in 1988 as compared to zero in 1980. By 1995, gas is expected to account for 51 percent of all the power generated.

The impact of the Malaysian Government's fuel diversification policy away from over-dependence on oil is clear. A policy mandate is very effective in developing a domestic gas industry.

In Indonesia, Pertamina, Indonesia's state-owned oil and gas company, is responsible for all activities related to the exploration and development of hydrocarbon reserves.[13,26] The main domestic production company is Pertamina. Gas is distributed by Pertamina and PGN, Indonesia's natural gas utility which distributes gas to some industrial customers and operates the city gas systems. International oil companies are involved in the exploration and production of natural gas via production-sharing contracts with Pertamina. The regulatory responsibility lies with the Ministry of Mines and Energy.

In 1973, Indonesia's oil production was about 490 x 10^6 bbl. Domestic consumption was about 130 x 10^6 bbl; the remainder was exported. However, natural gas production in 1973 was only about 0.06 x 10^6 BOE (0.35 x 10^9 CF). Essentially all gas production was used domestically since Indonesia had not yet entered the LNG export market. Since then, oil production, although peaking in 1977 and 1981, remained about the same from 1982 to 1989, while domestic consumption gradually increased to about 250 x 10^6 bbl/yr. But during this same period, natural gas production and domestic consumption have increased dramatically. By 1989, annual production had grown almost exponentially to about 240 x 10^6 BOE (1.4 x 10^{12} CF), and domestic consumption had increased to about 86 x 10^6 BOE (0.5 x 10^{12} CF).

The oil and LNG sectors have been critical to Indonesia's economic development during this period. While comprising only about 20 percent of the gross domestic product, these sectors contributed about one-half of the foreign exchange earnings and the Government's tax revenues. Indonesia's national energy policies incorporated in their 5-year plans (Repelita I to V) have been the driving force behind these changes. Although Indonesia has adequate natural resources, it lacks the capital and technology needed for exploration and production, so joint agreements have been made with foreign investors and companies to acquire the technology and capital. The resulting revenues have been used to support development of the infrastructure, and the Government has emphasized industrial growth supported by a strong agricultural sector. Until recent five-year plans (Repelita IV and V), the Government's position was that natural gas had a higher intrinsic value for export than as a domestic fuel, and a suitable infrastructure was not installed to permit expansion of the domestic gas industry. Current policies are directed to oil displacement by natural gas in industrial and power uses in domestic markets to conserve oil and to increase oil exports.

Good examples of Indonesia's current effort to increase domestic gas consumption are two projects aimed at substituting natural gas for oil and manufactured gas. One project involves expansion of the gas distribution systems of PGN in three cities: Jakarta and Bogor in Java, and Medan in Sumatra. The other project involves expansion of the supply of natural gas for Surabaya and twelve other towns in its vicinity in East Java, and further expansion of Medan's supply system. These projects involve a total of 185 miles of high-pressure pipeline, 568 miles of medium-pressure pipeline, and all associated service lines and equipment. Initial incremental gas sales from the first project are expected to be 54 x 10^6 CF/d when the project is completed in 1992, and 68 x 10^6 CF/d for the second project when it is completed in 1996. The total number of new customers expected from these projects is 750 industrial, 950 commercial, and 16,300 residential gas consumers.

In India, The Oil and Natural Gas Commission (ONGC), along with Oil India Ltd., produces all the hydrocarbons and also manages production-sharing contracts.[1] When the production of natural gas reached high volumes in the early eighties, the Government decided to set up a Gas Authority of India Ltd. (GAIL), to construct and own a trunk pipeline, buy gas from ONGC, and sell it to consumers, including power and fertilizer plants. To ensure coordination between production and utilization of gas, the Government is organizing a committee to periodically monitor progress in implementation of gas field developments and production plans, and in the construction of gas-consuming plants and facilities.

In Egypt, The Egypt General Petroleum Corporation (EGPC) functions as a holding company and has placed all direct petroleum activities in a number of wholly or partly owned subsidiaries and in operating partnerships with foreign oil companies.[1] Natural gas activities are now dominated by six organizations: EGPC through its natural gas department, three joint operating companies in ventures with foreign companies, and two wholly owned subsidiaries -- one for transmission pipeline construction and maintenance, and the other for distribution.

In Pakistan, the gas industry originated with the discovery of the Sui Field in the province of Baluchistan in 1952.[1] Deliveries from Sui commenced in 1955 with two distinct transmission and distribution systems (North and South), serving over one million customers. The infrastructure was developed with government and private foreign participation. These systems are operated by public companies, namely Sui Northern Gas Pipelines and Sui Southern Gas Company. They service over 90 major towns and cities throughout the country. Until 1971, natural gas had to compete with oil at oil parity prices. However, since the oil price hikes in the early seventies, the gas price was not raised proportionately. This led to a gradual reduction in foreign participation, shortages of gas supplies in the eighties, runaway demand for gas, and a reduction in funds available for gas exploration and development. The government is now divesting its direct interests to increase private shareholding and gas prices have been adjusted to be more competitive.

These summaries of the domestic gas industry infrastructures in a few developing countries indicate that many different permutations are possible. Some may be more successful than others, but it is clear that government policy and regulation are well established as a means promoting the development of a domestic gas industry.

Gas Pricing

Basic Principles. Next to sufficient proved natural gas reserves that are recoverable under current economic conditions with existing technology, the most important parameter is gas sales price. Unfortunately, this is not an inherent figure that can be calculated with precision. It is not necessarily related to true production cost or to supply and demand in an open energy market or to government controls or depletion allowances. LNG, for example, can be priced in long-term contracts by complicated formulas that incorporate a negotiated base price escalated to the spot price of crude oil or the current price of fuel oil in Singapore or the number and size of the shipments and a host of other variables. It was recently stated: "Indisputably, [LNG] price is central to viability and it is also a complex issue."[27] Above all, LNG must be priced sufficiently high to make it worthwhile for the parties involved to invest the huge capital required, yet not so high as to make fuel switching desirable.

In some countries, certain fuels are subsidized or taxed nonuniformly by government fiat thereby making the overall price structure artificial at best. The less tangible environmental and social values of natural gas have recently been introduced as well as potential carbon taxes and emissions credits to make it still more difficult to establish gas prices. In a real sense, the true cost of natural gas starting with gas in the ground cannot be determined with total accuracy since it is a depletable natural resource. But production, transport, and delivery costs can be measured with some degree of accuracy, along with capital costs and the desired return on investment, to provide a starting point in pricing gas. Overall, the product must still be priced competitively, and in many applications, can be the least-cost option.

For domestic markets, gas pricing has been a difficult and contentious issue in most gas-producing countries. There is no well defined international market for natural gas as there is for oil. On the one hand, gas prices must be set at a level to enable the recovery of costs and provide adequate returns for the producers. On the other hand, gas prices may be set at a level sufficiently low to encourage existing non-gas and new fuel consumers to use gas. Similarly, there may be a political or social imperative to provide gas at subsidized prices to encourage economic growth through lower costs of fuel and electricity. In the absence of a clear pricing methodology and policy, producers may be reluctant to explore or develop additional gas fields. On the demand side, the distortions in prices of energy products may encourage the excessive use of a given fuel source and prevent inefficient allocation of resources.

On the producers' side, a clear pricing policy is required on which the producer can estimate the likely range of wellhead prices. In general, the price to the producer should be negotiated on the basis of the costs of exploration and development. The prices to end-users are then built on producer prices with mark-ups for transmission and distribution. Differential pricing may be adopted on the basis of the differences in transmission/distribution costs, volumes of supply, nature of supply such as firm or interruptible, and the comparative ranking of economic benefits among consumers. Thus, the concepts of exhaustible resource pricing and of marginal and opportunity costs all need to be considered in setting a pricing structure.

Industrialized Countries. The natural gas price data for the U.S.A. presented in Table 12 are typical and illustrate the broad variability of gas pricing in a country that has a well established infrastructure and an open market. There are many reasons for the variability of gas pricing in the U.S.A.[22]* First, the Natural Gas Act of 1938 requires that the Federal Energy Regulatory Commission (FERC) regulate the prices interstate pipelines charge for their services, specifically transportation and gas sales for resale. The National Energy Strategy calls for reforming this regulation by allowing more flexible and market-responsive arrangements between pipelines and their customers, more competitive pricing of pipeline services, and more efficient utilization of the existing pipeline system. Individual states do not regulate the wellhead price, but they do regulate wellhead activities such as the spacing of wells on acreage and the prorating of production from wells and fields. Such regulation can significantly affect gas production. The public utility commissions (PUC's) in each state regulate local distribution companies (LDC's). Because regulatory reform has given LDC's new natural gas supply options, such as shopping for the lowest price from unregulated suppliers and several pipelines, the role of the PUC has become dominant. The advent of competition and greater reliance on market forces within the natural gas industry strongly suggest that individual state policies and PUC's will take on greater importance in the future. In any case, the gas industry and gas prices are subject to several layers of control, even in the open U.S. market. But the effects of supply, demand, and competition usually prevail in the long term.

Developing Countries. In developing countries, it would appear on the surface at least that gas pricing would be considerably simplified over the current procedures used in the U.S.A. Domestic gas pricing in a given developing country might be expected to be a more straight-forward exercise that can be based on economic principles. But developing countries at different stages of gas development have adopted different approaches to gas pricing. In general, consumer and producer prices are set so as to cover the marginal supply costs of gas without exceeding the prices of gas substitutes. In some developing countries, gas markets are initially developed by introducing gas at low subsidized prices in the early stages to encourage conversion to gas. With growth or expansion of the market, these subsidies may be discontinued to encourage further exploration (as in the U.S.A.) or to better utilize a valuable and relatively scarce commodity (as in Europe).

A rational approach to initiating a gas pricing calculation is based on summing the exploration, production, and transport costs of natural gas delivered to the distribution site, exclusive of taxes, royalties, and depletion allowances, as illustrated by the marginal cost estimates shown in Table 13 for several developing countries. These estimates serve as a

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*Note later discussion of end-use and netback value.

Table 12. SELECTED AVERAGE PRICES OF NATURAL GAS IN U.S.A. IN 1989[a]

Site	Average Annual Nationwide, $\$/10^3$ CF	Highest Monthly Average			Lowest Monthly Average		
		State	Month	$\$/10^3$ CF	State	Month	$\$/10^3$ CF
Wellhead	1.69	--	--	--	--	--	--
City Gate	3.01	--	--	--	--	--	--
Residential User	5.64	Hawaii	August	16.47	Alaska	March	3.56
Commercial User	4.74	Hawaii	June	12.05	Alaska	August	2.28
Industrial User	2.97	Rhode Island	February	6.36	Alaska	October	0.96
Utility	2.43	Virginia	December	6.34	Michigan	June	0.15
Overall Consumer	4.22	Hawaii	June	12.96	Mississippi	August	1.61

[a]Source: IGT's Energy Statistics and gasLine®.

Table 13. ESTIMATED MARGINAL COST OF NATURAL GAS DELIVERED TO MAIN MARKETS OF SELECTED DEVELOPING COUNTRIES[a]

Country	$\$/10^3$ CF
Bangladesh	0.24
Pakistan	0.36
Tanzania	0.61
Egypt	0.65
Nigeria	0.65
Tunisia	0.67
Thailand	0.80
India	0.95
Morocco	1.16
Cameroon	1.29

[a]Adapted from Table III.4 of Ref. 16. "Marginal cost" was estimated by dividing all discounted capital and operating costs by discounted gas volumes; the discount rate was 10 percent. The estimates are for 1989, and include exploration, production, and transport costs to the distribution site, but do not include taxes, royalty payments, or depletion premiums.

starting point to recover capital and operating costs to the city gate. The next step is to add the indicated costs excluded from the estimate and the distribution costs, if any. The resulting gas price would correspond to a simple cost of service to the consumer independent of end use, special discounts for volume usage, and government-imposed pricing parameters.

One of the important conclusions emerging from gas industry experience in developing countries is that the economic potential for industrial utilization of natural gas is far higher and more diverse than previously believed. The cost of delivering domestic gas to industrial users is generally well below the border price of imported fuels. In the majority of the gas-owning countries, delivered gas prices are generally quite low, ranging from $\$0.60/10^3$ CF to $\$2.50/10^3$ CF, the latter representing gas supplies from high-cost offshore fields. In most gas-producing countries, the total economic cost of gas - the marginal cost plus a depletion premium based on the price of the backstop fuel - is below the economic cost of alternative fuels. Typical marginal costs are listed in Table 13. An oil price as low as $15 per barrel in constant 1989 dollars would justify the development of most onshore and some offshore reserves in developing countries. Quite obviously, higher projections for future oil prices would justify gas development in remote locations, or offshore in deep waters.

End Use and Netback Value of Gas

Comparative analyses of end-use costs and efficiencies of gas and alternative fuels indicate that natural gas is an economically attractive fuel in countries with existing distribution networks to supply gas to the small and medium-scale industrial fuel markets. Gas end-use technology is usually lower in cost and higher in efficiency than technologies using oil or coal. In countries with established distribution networks, such as Pakistan, Argentina, and Bangladesh, the incremental cost of additional gas delivery is well below the economic cost of alternative fuels, typically the border price of imported petroleum. Natural gas is also particularly competitive in high-efficiency combustion applications, and consumers often attach a premium to the value of gas to take account of its desirable properties.

The value of natural gas as an industrial fuel or feedstock will be different in each end use, and vary from country to country, depending on the available production technology, the costs of alternative energy sources, and whether or not the end-product is exported or consumed domestically. A series of "netback values" have been estimated as a measure of the value of gas in alternative end uses (Table 14).[1,16] The netback calculations are based on country or location-specific parameters, and are primarily used to illustrate the economic competitiveness of gas vis-a-vis alternative options in a specific application, and to provide a basis for assessing the relative values of gas among a number of alternative end uses. Table 14 indicates that the netback value of gas in industrial applications is generally high relative to gas use in other end-use sectors. Within the industrial sector, the netbacks for gas are generally higher for industrial fuel uses than as chemical feedstock. Finally, export-oriented projects generally yield lower netbacks than those for domestic markets.

Table 14. ESTIMATED NETBACK VALUES FOR NATURAL GAS USAGE IN DEVELOPING COUNTRIES[a]

Use	Netback, $\$/10^6$ Btu[b]
Residential - Commercial	
Existing City Without Space Heating	2.00/5.40
New City With Space Heating	8.25/9.50
Power Generation	
Peak (New Diesel Thermal)	8.60
Base (Thermal)	5.25/7.75
Base (Hydro Coal System With Coal Replacement)	3.25/4.50
General Industry (Selected End Uses)	
Boiler Fuel	6.40/10.00
Fertilizer	
Developed Site, Domestic Market	5.63/8.75
Developing Site, Limited Infrastructure, Export Market	3.50/6.13
Developing Site, Limited Infrastructure, Domestic Market	5.40/8.40
LNG	
Small Scale, Limited Infrastructure	2.25/2.50
Large Scale, With Infrastructure	3.25

[a]Adapted from Ref. 1 and Table III.5 of Ref. 16.

[b]"Netback" is defined in Ref. 16 as the average value of gas in a particular application that would cause the project to break even and is estimated by dividing the present value of the net benefits of the project by the present value of the gas consumed in the project. Both the net benefits and gas volumes are discounted to take account of their differing time streams.

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