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Evaluating the Benefits to the Environment

John Homer

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Abstract

This paper promotes the cause of natural gas in the developing countries in the firm belief that their own natural gas resources offer significant opportunities for sustainable economic growth. Three factors support this view. First is the encouraging resource position where, as a rule, there are substantial reserves of natural gas in most developing countries. Second is the availability of large scale, highly efficient gas-fired power generation technology, which for reasons of lower capital cost and higher speed of construction is attracting a new wave of investment in the electricity industry of developing countries. Third is the environmental benefits of natural gas that help in the problem of urban air pollution and, because natural gas as a fuel emits less carbon dioxide than coal and oil, plays a role in governmental response to an international concern over global warming.

The paper describes the size of the natural gas resource in the developing countries, gives a broad indication of its costs, and outlines its main environmental benefits as an alternative fuel. It discusses the opportunities presented by new (and old) technology for using natural gas in an efficient way to reduce air pollution and relates that to recent developments in international concerns over the world's environment. The paper gives a perspective on the extent of flaring of natural gas in the petroleum industry and on the amount of emissions of the greenhouse gases of methane and carbon dioxide during production and use. It establishes a data source for many of the parameters necessary to derive both a country and a global perspective of the opportunities for natural gas.

The paper moves on to explore how the environmental benefits of natural gas can be valued with the aim of bringing that evaluation into decision processes on energy investment. Previous published reviews on the environmental benefits of natural gas have painted a strong but rather qualitative picture. This paper attempts to move more towards evaluating those benefits in a quantitative way and, where possible, describing them in economic terms. It examines three country case studies, and describes the way in which the respective governments approached the problems of severe air pollution and ascribe a high economic value to natural gas. The first reflects on the British Clean Air Act of 1956 and the role natural gas eventually played in solving the smog problems of London. The second examines the case of South Korea and analyses the expected improvements in urban pollution in Seoul and other cities. The third looks at Poland and relates its plans for increased gas use to the expected decrease in environmental damage especially in Southern Poland. The case studies paint a picture in which environmental value judgments, as well as least-cost solutions, are guiding the price at which communities are willing to pay for clean fuels like natural gas. It suggests that governments of developing countries would be helped by methodologies, which take local environmental damage into account in economic terms, in their choice of energy investment policies.

John Homer

Foreword

During the preparation of the World Development Report 1992, which was centered on the theme of the environment, we called on a number of experts to write working papers on special topics of interest. We asked John Homer, who was at the time working in the Natural Gas Development Unit of the World Bank in Washington to present the ideas that were current on the role which natural gas can play in energy and environmental strategies in developing countries.

The paper is an important one and worthy of the much wider audience which is reached through publishing in the World Bank Discussion Papers series. The paper is a good source of information on facts related to the natural gas opportunities in developing countries. I believe it also makes a special contribution to the debate on how the economic benefits of using a clean fuel such as natural gas can be considered and recognized. This is particularly well progressed in the Polish Case Study. It seems to be an important issue that governments are able to assess the full economic value of an environmentally beneficial fuel, or a related technology, so that better decisions can be made on investment priorities when both energy strategies and environmental targets are firmly on the discussion table at the same time.

Andrew D. Steer

Andrew D. Steer
Director
World Development Report 1992
The World Bank

Series Note:

World Development Report Background Papers

The World Development Report 1992, "Development and the Environment," discusses the posssible effects of the expected dramatic growth in the world's population, industrial output, use of energy, and demand for food. Under current practices, the result could be appalling environmental conditions in both urban and rural areas. The World Development Report presents an alternative, albeit more difficult, path - one that, if taken, would allow future generations to witness improved environmental conditions accompanied by rapid economic development and the virtual eradication of widespread poverty. Choosing this path will require that both industrial and developing countries seize the current moment of opportunity to reform policies, institutions, and aid programs. A two-fold strategy is required.

- First, take advantage of the positive links between economic efficiency, income growth, and protection of the environment. This calls for accelerating programs for reducing poverty, removing distortions that encourage the economically inefficient and environmentally damaging use of natural resources, clarifying property rights, expanding programs for education (especially for girls), family planning services, sanitation and clean water, and agricultural extension, credit and research.
- Second, break the negative links between economic activity and the environment. Certain targeted measures, described in the Report, can bring dramatic improvements in environmental quality at modest cost in investment and economic efficiency. To implement them will require overcoming the power of vested interests, building strong institutions, improving knowledge, encouraging participatory decisionmaking, and building a partnership of cooperation between industrial and developing countries.

World Development Report background papers in the World Bank's Discussion Paper series include:

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Margaret E. Slade (a) "Environmental Costs of Natural Resource Commodities: Magnitude and Incidence";
(b) "Do Markets Underprice Natural Resouce Commodities?"
Piritta Sorsa, "The Environment - A New Challenge to GATT?"
Sheila Webb and Associates, "Waterborne Diseases in Peru"

Other (unpublished) papers in the series are available direct from the World Development Report Office, room T7-101, extension 31393. For a complete list of titles, consult pages 182-183 of the World Development Report. The World Development Report was prepared by a team led by Andrew Steer; the background papers were edited by Will Wade-Gery.

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Note on Conversion Units

A paper of this kind covers by design a wide range of technical, economic and commercial aspects and has the problem of relating in a recognizable way to the variety of units used. International gas organizations and international agencies have generally adopted the conventions of the international system based on metric units, but the petroleum industry of the US and the commercial contracts of the international energy trade are a strong influence on retaining traditional units in discussions on the business of gas. In this paper, where those traditional units are used, conversion factors are also shown to allow the reader to relate always to the units of the international metric system. To clarify further (and perhaps to perpetuate the confusion) please note the following:

1 Bcm = 1 billion cubic metres = 10^9 cubic metres
1 Tcm = 1 trillion cubic metres = 10^{12} cubic metres
1 mcf = 1000 cubic feet
1 mmBtu = 1 million British Thermal Units = 1.055 GJ
1 ton = 1 metric ton .

1. Introduction

Natural gas has always been regarded as a premium fuel. It is non-toxic and burns with a remarkably clean and controllable flame, so giving considerable practical and economic benefits to industrial, commercial and residential consumers alike. It has been regarded also as somewhat of a scarce commodity, so that certain governments, particularly those of Western Europe, who found themselves in the position of being endowed with natural gas as well as having available other fuels such as coal, oil and nuclear, adopted a strategy of directing natural gas towards markets where its premium qualities could be of most benefit to society, and allocated the other fuels, more often than not in abundant supply, to the task of the industrial workhorse, in providing the base load supply of energy.

The last few years has seen an important change in attitude. From being reluctant to broaden the markets for natural gas, governments are now encouraging its wider use. This is especially so as a fuel for power generation. Such moves are taking place in many OECD countries and in Central and Eastern Europe, and international agencies, such as the World Bank, are encouraging similar moves in developing countries. Three factors have combined to bring about the change.

Firstly, the world's known reserves of natural gas which can be economically produced, are larger than ever before. Continuing exploration activity, as well as improvements in gas production technology, have steadily increased known reserves to about 700 billion barrels of oil equivalent, virtually equal to the amount of recoverable oil reserves, and equal to about 60 years of supply of natural gas at current rates of consumption. Furthermore, there is a confidence that exploration can reveal substantially more reserves. Governments can commit their countries therefore to a greater use of natural gas without undue risk of a fall off in supply.

Secondly, new developments in technology are making available large-scale, highly efficient, gas-fired power generation plants, which, for reasons of lower capital cost and higher speed of construction, are attracting a new wave of investment in the electricity industry.

Thirdly, and perhaps most importantly, is the strong international reaction to the growing problems of environmental pollution, and the strengthening realization that natural gas can help solve those problems of an immediate as well as long term future.

On the environmental side, there have also been major developments. Strongly intertwined with energy strategy issues of the last decade are the enormous changes in government thinking on environmental issues especially of air pollution. In the 1970's, it will be recalled, the main focus of environmental attention was on *local* pollution problems. During the early 1980's, this broadened to encompass *regional* air pollution problems, especially associated with acid rain, and so extended the debate to include transboundary pollution. Transnational discussion led to full *international* debate as the 1980's unfolded. A new threat to the world's environment arose in the form of the greenhouse effect, which was confirmed by a growing consensus of opinion from the scientific communities. The threat came from the ever increasing emissions of greenhouse gases, in part from the burning of fossil fuels, which could trigger a serious change in the balance of the world's climate, including that of a global warming. It has become an international issue of global dimensions.

2. Natural Gas Resource

2.1 The World's Natural Gas Resource

The world has sufficient proved reserves of natural gas to last 60 years at current consumption rates. The petroleum industry continues to find new resources. Total proved gas reserves increased by 12% in 1989 and by a further 1% in 1990 to a total of 130,000 X 10^9 m^3 (130 Tcm) which is equivalent to 700 billion bbl of oil equivalent and equal to 85% of the world's total oil reserves. Gas reserves are distributed widely across the world in 85 countries. Table 2.1 identifies the fifteen countries which have the largest reserves. The USSR has by far the most, with 40% of the world's reserves and Iran is second with 13%.

In comparison, Table 2.2 identifies the fifteen countries which *produce* most of the world's natural gas. By far the two largest are the USSR which produces 34% of the world's gas and the USA which produces 24%. Note that the table gives figures for gross production: in total, 9% of that gas is reinjected into the fields, 4% is flared, 5% is consumed in production and transmission, leaving 82% to be marketed.

2.2 Natural Gas Resources in Developing Countries

Almost half of the world's natural gas reserves are in developing countries and the long term supply situation is strong in many of them. In comparison they ***produce only 15% of the world's gas production.*** The ratio of total reserves to total current production is as much as 140 years for the developing countries which have proved gas reserves. It is expected to be even more plentiful than that. A generally accepted view is that proved reserves of natural gas often are understated since the delineation of gas reserves is much less precise and more conservative than that of crude oil. To date there has been relatively little exploration in developing countries. Natural gas reserves have been identified mainly while exploring for oil and it is expected that additional gas reserves, some of them being large, will be discovered as gas markets are developed and gas exploration becomes economically attractive.

A listing of the developing countries which have proved natural gas reserves is given in Table 2.3. It shows the extent of natural gas resource and natural gas consumption as given by the 1991 Report on Natural Gas published by Cedigaz .

Table 2.1 Top Fifteen Countries in the World for Natural Gas Reserves

Country	Proved Gas Reserves (Tcm) 1990	1991	% World 1990
USSR	52.0	53.0	40%
Iran	17.0	17.0	13%
Abu Dhabi	5.2	5.2	4%
Saudi Arabia	5.2	5.2	4%
USA	4.7	4.8	4%
Qatar	4.6	4.6	3%
Venezuela	3.0	3.4	3%
Algeria	3.2	3.3	3%
Iraq	3.1	3.1	2%
Nigeria	2.8	2.8	2%
Canada	2.7	2.8	2%
Indonesia	2.6	2.6	2%
Norway	2.3	2.3	2%
Australia	2.1	2.1	2%
Mexico	2.1	2.0	2%
70 others	17.6	17.6	13%
Total World	130.2	131.8	100%

Source: Cedigaz

Table 2.2 Top Fifteen Countries in the World for Natural Gas Production

Country	Gross Gas Production (Bcm) 1990	1991	% World 1991
USSR	825	844	34%
USA	595	604	24%
Canada	137	137	5%
Algeria	120	127	5%
Netherlands	72	72	3%
Indonesia	56	59	2%
UK	52	58	2%
Saudi Arabia	47	49	2%
Iran	43	46	2%
Venezuela	38	41	2%
Mexico	37	38	2%
Norway	39	37	1%
Rumania	32	29	1%
Nigeria	25	28	1%
Argentina	24	23	1%
55 others	324	322	13%
Total World	2,466	2,514	100%

Source: Cedigaz

Table 2.3 Developing Countries with Proved Natural Gas Reserves
(1989 economic data and 1990/91 gas data)

Country	Natural Gas Reserves (Bcm)	Natural Gas Consumption per year (Bcm)	Natural Gas Reserves / Natural Gas Consumption (years)	Natural Gas Consumption / Total Energy Consumption
Iran	17,010	24	718	44%
United Arab Emirates	5,623	18	311	113%
Saudi Arabia	5,184	31	170	44%
Venezuela	3,429	18	186	33%
Algeria	3,300	19	178	36%
Iraq	3,107	4	740	28%
Nigeria	2,807	4	759	24%
Indonesia	2,568	43	59	83%
Mexico	2,024	27	76	22%
Malaysia	1,640	19	89	104%
Kuwait	1,394	7	194	65%
Libya	1,208	6	195	42%
India	1,095	11	97	5%
China	1,005	14	70	2%
Bangladesh	734	5	153	77%
Argentina	660	29	23	48%
Pakistan	642	14	45	54%
Trinidad and Tobago	457	5	91	64%
Egypt	353	8	44	23%
Peru	339	1	308	9%
Oman	283	3	101	89%
Myanmar	265	1	294	28%
Papua New Guinea	241	-	-	-
Thailand	224	6	38	29%
Yemen	198	-	-	-
Bolivia	190	3	63	159%
Syria	182	3	63	24%
Poland	130	13	10	9%
Colombia	124	4	29	16%
Hungary	118	11	11	31%
Tanzania	118	-	-	-
Brazil	115	3	41	2%
Chile	113	1	103	9%
Ecuador	111	0	1110	1%
Cameroon	110	-	-	-
Romania	105	37	3	40%
Afghanistan	100	0	333	-
Côte d'Ivoire	100	-	-	-
Other Countries (21)	744	19	39	8%
Total	58,150	411	142	17%

Sources: World Bank and Cedigaz

The above Table 2.3 was designed to highlight those developing countries with the greatest resource in natural gas. Of importance is to identify, alongside, those developing countries with the *greater economic need.*

The next two tables, Tables 2.4 and 2.5, list those developing countries with proved natural gas reserves, *in order of increasing GNP per capita.* The numbers are compared with the basic economic data for each country for population, GNP per capita and total consumption of commercial energy which are taken from the 1991 World Development Report of the World Bank. The countries are shown in the tables, grouped into low and middle income economies as categorized by the World Bank report.

Table 2.4 Natural Gas Reserves in Low-Income Economies
(1989 economic data and 1990/91 gas data)

Country	GNP per capita $	Population (millions)	Total Energy Consumption per year (millions toe)	Natural Gas Consumption per year		Natural Gas Reserves (Bcm)
				(millions toe)	(Bcm)	
Mozambique	80	15	1.3	-	-	65
Ethiopia	120	50	1.0	-	-	25
Tanzania	130	24	0.9	-	-	118
Somalia	170	6	0.5	-	-	6
Bangladesh	180	111	5.6	4.3	4.8	734
Madagascar	230	11	0.5	-	-	2
Nigeria	250	114	15.4	3.3	3.7	2,807
Zaire	260	35	2.5	-	-	1
Rwanda	320	7	0.3	-	-	57
India	340	833	188.1	10.2	11.3	1,095
China	350	1,114	658.3	13.0	14.4	1,005
Pakistan	370	110	23.4	12.9	14.3	642
Guinea	430	6	0.4	-		24
Indonesia	500	178	46.9	38.9	43.2	2,568
Afghanistan	-	-	-	0.3	0.3	100
Myanmar	-	41	2.9	0.8	0.9	265
Sudan	-	25	1.4	-		86

Sources: World Bank and Cedigaz

Table 2.5 Natural Gas Reserves in Mid-Income Economies
(1989 economic data and 1990/91 gas data)

Country	GNP per capita $	Population (millions)	Total Energy Consumption per year (millions toe)	Natural Gas Consumption per year (millions toe)	Natural Gas Consumption per year (Bcm)	Natural Gas Reserves (Bcm)
Angola	610	10	-	0.4	0.5	50
Bolivia	620	7	1.7	2.7	3.0	190
Egypt	640	51	32.4	7.3	8.1	353
Yemen	650	11	1.1	-	-	198
Côte d'Ivoire	790	12	-	-	-	100
Morocco	880	25	6.0	0.1	0.1	3
Papua New Guinea	890	4	0.9	-	-	241
Congo	940	2	0.5	-	-	77
Syria	980	12	10.8	2.6	2.9	182
Cameroon	1,000	12	1.6	-	-	110
Peru	1,010	21	11.0	1.0	1.1	339
Ecuador	1,020	10	6.7	0.1	0.1	111
Colombia	1,139	32	24.4	3.9	4.3	124
Thailand	1,220	55	18.0	5.3	5.9	224
Tunisia	1,260	8	4.4	1.4	1.5	86
Turkey	1,370	55	46.0	3.2	3.5	28
Jordan	1,600	4	3.0	0.1	0.1	15
Chile	1,770	13	10.9	1.0	1.1	113
Poland	1,790	38	126.3	10.6	11.8	130
Mexico	2,010	85	109.0	24.0	26.6	2,024
Malaysia	2,160	17	16.0	16.7	18.5	1,640
Argentina	2,160	32	54.8	26.1	29.0	660
Algeria	2,230	24	46.5	16.7	18.5	3,300
Venezuela	2,450	19	49.8	16.6	18.4	3,429
South Africa	2,470	35	85.1	-	-	51
Brazil	2,540	147	132.0	2.5	2.8	115
Hungary	2,540	11	32.9	10.1	11.2	118
Yugoslavia	2,920	24	53.1	6.2	6.9	82
Gabon	2,960	1	1.3	0.1	0.1	12
Trinidad and Tobago	3,230	1	7.0	4.5	5.0	457
Oman	5,000	1	2.8	2.5	2.8	283
Libya	5,220	4	13.4	5.6	6.2	1,208
Greece	5,350	10	20.5	0.1	0.1	6
Iran	-	53	54.3	21.3	23.7	17,010
Iraq	-	18	13.8	3.8	4.2	3,107
Romania	-	23	81.5	32.9	36.5	105

Sources: World Bank and Cedigaz

2.3 *Economics of Natural Gas Production in Developing Countries*

Countries having large reserves of natural gas have a good chance of developing the resource in an economic way, but countries with small reserves can have difficulty justifying the initial hurdle investment for building a production facility and installing the necessary gas transmission and distribution network.

A good guideline for the smallest size production facility that is sensible economically, is for a gas reserve of perhaps 5 Bcm, which, for a twenty year project, is large enough to fuel a 150 MW_e power station. Almost all the developing countries listed above have gas reserves greater than this amount.

The cost of production would vary according to circumstances. Studies carried out by the World Bank estimated that the marginal cost of natural gas, delivered into the country's gas transmission system, is in a range from $0.24 to $1.29/mcf across ten developing countries with diverse geological location, market, and gas qualities. Table 2.6 gives the estimate of marginal coats for the individual countries examined together with the proved gas reserves for the country:

Table 2.6 Estimated Marginal Cost of Natural Gas

Country	Natural Gas Reserves (Bcm)	(Tcf)	Marginal Cost ($/mcf))
Nigeria	2,807	104	0.65
India	1,095	41	0.95
Bangladesh	734	27	0.24
Pakistan	642	24	0.36
Egypt	353	13	0.65
Thailand	224	8	0.80
Tanzania	118	4	0.61
Camaroon	110	4	1.29
Tunisia	86	3	0.67

Sources: World Bank and Cedigaz

An important conclusion of the World Bank study was that the total economic cost for supply of natural gas, including this marginal cost as well as a depletion value based on the price of fuels it would replace, is below the economic cost of alternative fuels. The cost of alternative fuels varies according to the individual circumstances of the country, but it has become normal economic practice, in general guidance to developing countries regarding long term policy decisions on energy investment, to compare those costs with the border prices of international trade.

Table 2.7 below gives therefore, for comparison, the energy prices for imported fuels which are typical of present day international trade. For cross reference, fuel prices are converted in the last column of the table, to the common unit of $/mmBtu.

The broad conclusion of the comparison is that ***natural gas can be produced from indigenous sources at costs which are much lower than the cost of importing oil and gas and, in many cases, lower than the cost of importing coal.***

Table 2.7 Equivalents for Representative International Fuel Prices

Fuel	($/bbl)	($/ton)	($/mcf)	($/mmBtu)
Oil	20			3.4
Steam Coal		50		1.2
Pipeline Natural Gas			2.5	2.5
LNG			3.5	3.5

2.4 Further Resources of Natural Gas

Besides proved reserves and, as yet, undiscovered reserves, there are several "unconventional" sources of methane. Some of these sources of gas are being produced commercially in some countries but much of them await improved technology, or an increase in fuel price, to permit economic production on a large scale. Some of these resources are huge, vastly greater than conventional reserves in some countries, and while most of the attention to date has been in North America, similar geological formations are known to exist elsewhere in the world but have not yet been appraised.

The "unconventional" gas reserves are:

- *coalbed methane* which is a substantial resource associated with the world's coal deposits, and which is being increasingly used either by trapping the methane vented from deep coal mines or being produced from wells drilled through multiple seams of a coal field (the US makes significant use of this resource and there is a real expectation that Poland and China will also develop substantial gas production from similar resources in the near future),

- *tight gas formations* where the gas is held in rocks of low permeability and requires rock fracturing techniques to encourage useful production,

- *shale gas* deposits which are the Devonian shales, rich in organic matter, but very reluctant to release their natural gas,

- *gas hydrates* which are present in permafrost or in seabeds, with huge estimates of reserves, but an economic production which has to be highly speculative,

- *geopressured aquifers* where gas is dissolved in water at the very high pressures found deep in the ground, again with huge reserve estimates, but again regarded as highly speculative as a usable resource.

2.5 Gas Qualities

Natural gas resources range in quality from being "dry", containing mostly methane, through being "wet", when they have significant amounts of higher hydrocarbons - ethane, propane, butanes, pentanes - to being fully "associated" with crude oil and, in which case the gas emerges from the well at the same time as oil is produced. The higher hydrocarbons in "wet" gas can be physically condensed out and can be a useful source for commercial Liquefied Petroleum Gas (LPG) and gasoline fuels. Some typical compositions of natural gases and of LPG which are being produced are shown for reference in Table 2.8. Also shown are examples of a low calorific value gas which has significant amounts of nitrogen, and a sour gas which has high amounts of sulphur in the form of the highly toxic hydrogen sulphide.

Table 2.8 Natural Gas/LPG Qualities

Component Analysis (volume %)	Natural Gases				Commercial LPG		
	Dry	Wet	Low CV	Sour	Propane	Butane	LPG
Methane	99.2	87.0	72.3	58.7			
Ethane		4.1	14.4	16.5	2.2		
Propane		2.4		9.9	97.3	6.0	50.0
Butanes		2.0		5.0	0.5	94.0	50.0
Pentanes +		3.4		3.5			
Hydrogen Sulphide				6.4			
Carbon Dioxide	0.2	1.1	0.5				
Nitrogen	0.6		12.8				
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Net Calorific Value (Btu/cf gas)	906	1,109	898	1,359	2,358	2,961	2,759

The sour gas has to be processed so that the hydrogen sulphide can be removed to produce a natural gas with levels of sulphur typically below 3 ppm. The sulphur is burnt off as SO_2, or is, where local pollution problems require it, trapped chemically as a sulphate and disposed of safely. Sour gas wells obviously have lower value, although sometimes the amount of hydrogen sulphide is high enough to make it to be a commercial source of sulphur.

2.6 *The Practice of Gas Flaring*

Often, associated gas, which is produced at the same time as oil, can find an economic use as a fuel for local markets, or alternatively can be re-injected back into the oil field to maintain the field pressure. Sometimes it is not commercially or technically feasible to do either and the gas is then best flared. The practice of gas flaring is always under scrutiny. Governments prefer to see the country's gas resources used in better ways than just being flared off, and many force the producing oil companies to use or conserve the resource as a condition of oil production. Recently the international community has become more interested in the practice, partly in concern over unnecessary wasting of the world's resources, and partly over the recognition of the harm that excessive emissions of CO_2, a major component of burning the gas, might have on global warming.

The extent of gas flaring in the world is significant. It can be regarded as an already available and inexpensive source of energy for the country concerned. The following Table 2.9 identifies the countries which currently flare large amounts of gas.

Table 2.9 Top Ten Countries in the World for Gas Flaring
(1990)

Country	Amount of Gas Flared and Vented	
	(Bcm/year)	(% of total gas produced)
Nigeria	21	76
USSR	19	2
Algeria	7	5
Venezuela	5	13
Saudi Arabia	5	11
India	5	30
Libya	5	31
Indonesia	5	9
Iraq	5	50
USA	4	1
Others	26	3
Total World	107	4

Source: Cedigaz

Of the developing countries, Nigeria, India, Libya and Iraq are outstanding in the proportion of gas which they flare. Programs for utilization of flared gas in developing countries are being promoted with technical and financial assistance through the World Bank. Those programs have been a part of the normal energy sector lending work of the Bank and have been reinforced recently by the establishment of the Global Environmental Facility fund which is aimed, in part, at reducing unnecessary emissions of greenhouse gases.

3. Natural Gas Use and Environmental Emissions

3.1 Clean Fuel Characteristics of Natural Gas

Many studies and reports have detailed the environmental benefits of natural gas. It has three major benefits:

- it contains no solid particles or inorganic materials, and so does not give rise to particulate emissions, or to the production of ash,
- it contains normally only trace amounts of sulphur and so does not give rise to the kinds of SO_2 emissions which are characteristic of the burning of coal and fuel oils; and,
- it contains less carbon and more hydrogen than coal and oil, and so gives lower amounts of CO_2 per unit of useful energy output.

These are significant advantages for industries and governments concerned with national and international environmental issues. The only significant air pollutant produced from burning natural gas remains that of the nitrogen oxides (NO_x) formed from the simultaneous oxidation of the nitrogen in the air. New burner designs can minimize these emissions so that in most bulk applications they are smaller than the emissions from the burning of coal and oil, but they cannot be ignored and can still be significant in the pollution problems of smog and acid rain.

The alternative clean energy supplies of hydroelectric power, geothermal, the renewables (wind, waves, solar) and of nuclear have the advantage of also producing no NO_x and, with the exception of some geothermal sources, no CO_2. Hydroelectric power and geothermal sources are used wherever possible, and should be used wherever it is commercially and environmentally sensible to do so. Renewable forms of energy have also a real part to play in attacking the problems of air pollution, but, as yet, have rather limited application, and generally await breakthroughs in technology which can lower their costs substantially. Nuclear energy also has an important and large contribution to make, but there, investment in new nuclear power plants in many countries is delayed by problems, which are not solved yet, of the disposal of radioactive waste, and of regaining full public confidence over operational safety issues.

Natural gas can be described as a fuel which is relatively benign to the environment. It is a very acceptable technically as a fuel for power generation and for residential, commercial and industrial applications. It has long been used as a chemical feedstock and is also being considered as a possible fuel for wider use in vehicles. The following Sections 3.2 - 3.5 examines in greater detail the environmental aspects of these applications. The two Sections 3.6 and 3.7 after that, considers the environmental impact of the supply chain which delivers natural gas to the consumer. That will provide a good grounding for the discussion of the evaluation of the environmental benefits of natural gas to be developed in Section 4.

3.2 Use of Natural Gas in Power Generation

The development over the last two decades of large (150 MW_e) efficient (35%) gas turbines offers developing countries with natural gas reserves the prospect of a lower cost electricity supply. Modern gas-fired power stations use combined cycle technology in which the hot exhaust from a gas turbine is used to generate steam which drives a steam turbine. As a result, the thermal efficiency is high, even as high as 50%. At the same time, the capital costs of the technology are relatively low, at about $600/kw of installed electrical capacity. Using natural gas for electricity production instead of oil or coal, minimizes the environmental impact of power generation from fossil fuels. ***Combined cycle technology then has the great potential of providing cheaper electricity for developing countries with access to natural gas reserves while at he same time also significantly improving the environment.***

Coal-firing dominates power generation in developing countries, providing 45% of their electricity. This dominant position will be maintained in the next decade during which the total electricity production in developing countries is expected to double (see "Capital Expenditure for Electrical Power in Developing Countries in the 1990's ", World Bank IEN Paper No. 21, February 1990) The share of natural gas in the power generation market in developing countries is expected to grow from 5.9% to 8.6% in that period.

Recent analysis (see "Prospects for Gas-Fueled Combined-Cycle Power Generation in the Developing Countries", World Bank IEN Paper No. 35, May 1991) shows that for base-load power generation, and in competition with fuel prices for coal at $40/ton and for residual oil at $15/bbl, gas-fired combined cycle is the least cost solution for gas prices up to $3.30/mmBtu for large systems (450 MW_e) and up to $4.10/mmBtu for small systems (90 MW_e).

To indicate the environmental advantages of natural gas in power generation, the following Table 3.1 shows the physical activities on a new 450 MW_e power station depending on whether it is fueled by coal, oil or natural gas.

Table 3.1 Daily Activity of a 450 MW_e Power Station

Fuel	Plant Type	Energy Efficiency	Fuel Used (tons)	Waste Solids (tons)	Waste Heat (GWH)	SO_2 Emitted (tons)	NO_x Emitted (tons)	CO_2 Emitted (tons)
Coal*	• Conventional	38%	3,600	450	17	75	10-35	9,000
	• with 90% FGD	37.5%	3,650	590	17	8	10-35	9,100
Oil*	• Conventional	39%	2,250	1	17	170	7-15	7,500
	• with 90% FGD	38.5%	2,280	300	17	17	7-15	7,600
Gas	• Conventional	40%	2,100	0	16	0	3-15	6,000
	• Combined Cycle	48%	1,750	0	13	0	2-10	4,500

** Sulphur content taken as 1% for coal and 3.5% for oil*

In comparison to conventional coal-firing, the 450 MW_e natural gas-fired combined cycle plant:

- avoids the disposal problems and costs of about 500 tons of solid waste *per day*
- reduces the waste heat by 25%
- eliminates the SO_2 emissions
- halves the CO_2 emissions

Managers of coal-fired power stations in some countries, whose operations are severely constrained by legislation limiting pollutant emissions, find it to their advantage to co-fire their boilers with up to 30% of natural gas. This market for gas, recognizing its environmental value, is expected to grow in coming years in developing countries as it has done elsewhere.

3.3 Use of Natural Gas in Residential, Commercial and Industrial Markets

Natural gas has long since established itself in mature energy markets in applications where cleanliness is important. For residential and commercial markets, it has particular benefits for direct heating in cooking and, in countries with cold climates, in space heating applications. In cities of high population density where air pollution is a problem, it is chosen increasingly as the preferred fuel and its use enforced by legislation to deny consumers the use of the more polluting fuels of firewood, coal and high sulphur fuel oils. There are a number of countries where natural gas has played a major role in helping to solve the problem of high pollution loads emitted to the atmosphere from the residential sector especially. This factor can be easily recognized in the three cases studies to be described later in Section 4.

The cost of distribution of natural gas to a large number of small consumers can be expensive. The developments of such markets often depends on the proximity of gas transmission pipelines which have been financed already through major gas supply projects to the power and industrial sectors. Even so, the commercial price that has to be considered for natural gas supplied to the residential market is still high on a $/mmBtu basis. That price can be justified where air pollution loads are too high and the cost of alternative means to reduce pollution emissions becomes equally high.

The emissions from small gas-fired heaters or boilers are much lower than for those fired by firewood, coal, or fuel oil. The following Table 3.2 gives an indication of these relative emissions in terms of kg of material emitted from the flue stack per unit of energy *in the fuel*. A calculation of emissions per unit of energy *used*, involves an analysis of the technology employed and the practice of the consumer. Some of the older coal burning grates, for example, can give much higher emissions per unit of useful energy than indicated in this table.

Table 3.2 Combustion Emission Indices for Residential and Commercial Applications (g/GJ)*

Plant System	Particulates	SO_2	NO_x	CO_2
• Residential				
- hard coal**	176	481	50	90,000
- gas oil**	1.5	95	50	72,000
- natural gas	0.1	0.5	50	51,000
• Commercial				
- hard coal**	50	572	122	90,000
- gas oil**	1.5	94	50	72,000
- natural gas	0.1	0.5	40	51,000

* *1 mmBtu =1.055 GJ*

** *Sulphur content ~ 1% for hard coal and 0.2% for gas oil*

Source: "Gas - the Solution: A Route to Sustainable Development" issued by the International Gas Union in July 1991.

For large commercial applications and in smaller industrial boilers also, natural gas can be the fuel of choice on economic grounds, competing successfully with coal and oil fuels for which applications are burdened with the extra cost of installing combustion emission controls. For large industrial applications, however, coal-firing and oil-firing is cheaper more often than not. This follows because at some point in the cost-versus-size curve the unit cost of emission control becomes economically tolerable.

Just as in the case of combined cycle power generation where gas can be consumed at high thermal efficiency, so, in some industrial and commercial applications, higher efficiencies of combined systems and technologies are having an important impact.

Co-generation is one such technology which is the sequential production of power (electrical or mechanical) and thermal energy (as steam or heat) within one system. Co-generation processes make use of the waste heat produced in conventional electricity generation, so that the overall process becomes more thermally efficient. Natural gas fired co-generation, with either gas or steam turbines, is also better than coal-fired steam turbine co-generation which have to be fitted with additional flue gas equipment to reduce the emissions of particulates and SO_2. The following Table 3.3 compares the annual emissions of the example of a co-generation plant producing 11 MW_e of electricity and 9 tons of steam per hour at a 70% capacity utilization, with those from the conventional, separated, system.

Table 3.3 Atmospheric Emissions from a Co-generation Plant
(tons/year)

Plant System	Particulates	SO_2	NO_x	CO_2
• Conventional System				
- oil-fired steam + coal-fired electricity*	90	1,060	410	206,000
• Co-generation Systems				
- steam turbine - coal *	100	1190	700	188,000
- steam turbine - gas	10	70	70	107,000
- gas turbine	3	15	140	111,000

** including flue gas desulphurization and electrostatic precipitators*
Source: Nelson Hay, American Gas Association

In comparison to the conventional system, the gas-fired co-generation gas turbine system:

- virtually eliminates the particulate and SO_2 emissions
- reduces NO_x emissions by a factor of three
- halves the CO_2 emissions

Other more recent technologies may become important for commercial and residential markets. There are R&D programs to be found in Japan and the USA on fuel cells designed to produce electricity from natural gas. There have also been developments in commercializing new air conditioning units fueled by natural gas. Both applications are expensive and not competitive with normal methods of electricity generation and traditional electric powered air conditioning units, to be considered for active promotion in developing countries at present.

3.4 *Use as a Fuel for Vehicles*

Of the 500 million motor vehicles on the world's roads, only 600,000 or 0.1% are fueled by natural gas. That statistic is overwhelming in confirming that traditional liquid fuels of gasoline and diesel are the more economic and more convenient to distribute and use. Natural gas for vehicle use is a Compressed Natural Gas (CNG) which is stored in high pressure cylinders on the vehicles. The extra costs of such tanks and the extra costs of distribution and installing filling stations throughout a country have been major disincentives for developing this market.

And yet natural gas has technical advantages in its cleanliness and can offer cities suffering from air pollution some relief. It can result in:

- a 50 - 80 % reduction in carbon monoxide emissions
- a 40 - 90 % reduction in the emissions of reactive hydrocarbons

Both of which are beneficial to the air quality of urban areas.

The most economic application is as a fuel for fleet vehicles and city transport buses which have a home depot and a relatively short range of operation. Several cities in developing countries have trial activities. The World Bank has provided assistance for CNG programs in the developing countries of Argentina, Bangladesh, Bolivia, Brazil, Colombia, Indonesia, Malaysia, Mexico, Pakistan, Thailand, and Trinidad.

For such countries, the attractiveness of CNG for vehicles is partly for environmental reasons but mainly aimed at making strategic use of their own natural gas resources, while avoiding imports of oil products or allowing their own oil to earn foreign currency through export. The extent of the market for natural gas is quite small in total but should be facilitated where it is strategically and economically sensible to do so.

3.5 *Use as a Chemical Feedstock*

More than 70% of the world production of ammonia depends on natural gas and almost all this ammonia goes into the production of fertilizer. Its high hydrogen content make natural gas an ideal feedstock for this industry, and the cleanliness of the fuel give it additional advantages over coal.

Natural gas also finds its way into methanol production, gasoline production, and most recently, with the development of Shell's technology, in the production of diesel fuels and aviation fuels. An important advance in the Shell work is that the diesel fuels derived from the process are uniquely clean in being free of sulphur and having much lower tendency to form soot from diesel engines. While these fuels derived from gas are more expensive than their oil product competitors, they have an environmental benefit which imparts a premium value as a blend component as well as a stand-alone fuel.

3.6 Gas Leakage

There are two environmental issues which have been the subject of recent active investigation and discussion. Both are over the atmospheric emissions that take place as part of the normal way of producing and transporting natural gas. Both relate to the global concern on excessive emissions of greenhouse gases: the first concerns the extent of leakage of methane or the amount vented in normal safety and maintenance operations, the second concerns the amount of CO_2 produced during natural gas production and transport operations.

Publicity in 1989, on the issue of methane leakage from gas pipelines, had advertised an average industry figure for loss rates as high as 10%, but closer analysis of existing systems and more detailed reporting by the gas industry has been able to confirm much lower figures. The data is still not complete, but the latest international expert committees are reporting average figures for natural gas leaks are between 0.2% and 2% depending on the country of operation.

The problem is that methane is a very active greenhouse gas, being reported as 20 times more active than CO2 on a relative molecular basis (see the report of the Intergovernmental Panel on Climate Change published in 1990). As demonstrated earlier, an advantage of using natural gas as a fuel for a power station, in preference to coal, is that it emits only half the amount of CO_2. It can be calculated that this advantage of helping with the global warming problem would be lost if methane leaked from the system supplying gas to the power station, at rates over about 3%.

The leakage from a pipeline system depends on whether it is a large-diameter transmission line or whether it is a network of smaller diameter multi-joint distribution pipework. It also depends on age and the state of repair. Gas leaks are repaired quickly, for safety as well as commercial reasons, but the amount of money spent on maintenance of pipelines is not always as high as it should be. As a guidance, which is by necessity a broad one, the following Table 3.4 gives the leak rates that can be expected in the various gas pipeline systems.

Table 3.4 Leakage from Natural Gas Pipeline Systems
(representative numbers for % of throughput)

New Transmission Lines	< 0.1%
Existing Transmission Lines	0.01% - 2%
New Distribution Networks	< 0.5%
Existing Distribution Networks	0.2% - 6%

Sources: Shell, World Bank, Alphatania and the IPCC Working Group

There are two messages for natural gas projects in developing countries. Firstly is a re-emphasis of the importance of maintenance and replacement programs for leaking pipework, not only for safety reasons but, now, also for global warming reasons. Secondly is that for ***new*** natural gas supply system, constructed according to good modern engineering standards, natural gas leak rates of **less than *0.1%*** of throughput can be expected and, if achieved, present no detriment to the advantages of natural gas in helping with the global warming issue.

3.7 *CO_2 Emissions during Production and Transport*

Gas transport systems consume energy themselves in the process of moving gas from the production well to the consumer. The amount of energy used obviously depends on distance. For very large distances, the amounts of energy required can be significant. This gives rise to two concerns: firstly as a cost item, because less gas is delivered as a result, and secondly as a source of CO_2 which is of concern to global warming. A pipeline of 4000 km, using its own gas as a fuel for its compressors, could consume 10% of its throughput, and emit a corresponding amount of CO_2. For Liquefied Natural Gas (LNG) projects, the consumption is higher, about 20% of the delivered gas, made up from perhaps 3% used upstream of the LNG plant, about 10% in the liquefaction step and a further 5% in the shipping and downstream systems. These figures compare (Table 3.5) with those for the long distance bulk supply of coal of perhaps between 5 and 10% of the energy being consumed in its production (mining) and transport link.

Table 3.5 Energy Consumed in Fuel Production and Supply
(representative numbers for % of energy delivered)

Fuel	Short Distance Supply (e.g. <100 km)	Long Distance Supply (e.g. >4,000 km)
Coal	3%	5%-10%
Gas by pipeline	1%	10%
Gas by LNG	-	20%

Source: Shell

The comparison of the amount of CO_2 emitted from gas supply chains has been questioned because it detracts from the advantages demonstrated earlier of its ability in a power station to produce 50% less CO_2 than coal, per unit of produced electricity. The above Table 3.3 shows that over short distances, natural gas emits less than coal, but for long distance supply, where imported LNG is compared with locally produced coal, the overall gains for natural gas are less.

Many commercial gas fields produce gas containing a small amount of CO_2, but generally of no significant consequence to the global environment. (It has to be considered though in another context of avoiding corrosion of the pipe walls and often has to be extracted by chemical means before transmission.) Some gas fields have very high CO_2 levels which usually makes them uneconomic. In an era of concerns over global warming, they are even less favored as a fuel source. Some of the natural gases used as feedstocks to the LNG trade in the Far East have 5%, and in one case14%, content of CO_2 by volume; this CO_2 is separated out and normally vented before the gas is fed to the liquefaction plant. The effect of this on presenting LNG as a fuel which can reduce the CO_2 emitted from power stations comes under question, but can be shown to be not all that significant: from a calculation comparing coal and LNG as fuels imported to produce electricity, it can be shown that the CO_2 content of the natural gas feeding into the LNG plant would have to be *greater than 50%* by volume before the LNG supply system and the gas-fired power station combined, produces more CO_2 than the corresponding coal-fueled route.

4. Assessment of Environmental Benefits

Having now established in the previous sections a reference source for the natural gas resource and for its environmental benefits as a fuel in terms of lower emissions to the atmosphere, let us turn now to the subject of air pollution itself and develop a better picture of what real contribution natural gas can make and how *valuable* an impact natural gas can have on improving the environment of the developing world.

4.1 Concerns over Air Pollution

A review of the last two decades can identify enormous, quite radical, changes in government thinking on environmental issues especially over air pollution. In the 1970's, the main focus of environmental attention was on *local* pollution problems. During the early 1980's, this broadened to encompass *regional* air pollution problems, especially those associated with acid rain, and in the process extended the debate to include transboundary pollution. Transnational discussion led to full *international* debate as the 1980's unfolded. A new threat to the world's environment arose in the form of the greenhouse effect, which was confirmed by a growing consensus of opinion from the scientific communities. The threat came from the ever increasing emissions of greenhouse gases, in part from the burning of fossil fuels, which could trigger a serious change in the balance of the world's climate, including that of a global warming.

Section 3 previously identified how natural gas clearly has something to offer the environment in all three spatial aspects: local, regional and international. Its non-polluting properties regarding SO_2 and particulate emissions, gives natural gas the role of helping to solve local and regional air pollution problems. Its lower CO_2 emissions are now recognized as offering immediate help to the international problem of global warming.

Environmental benefits equate to economic value. Natural gas has an economic value which is higher than a competing, but more polluting, fuel, by an amount which is equal to the incremental economic environmental benefit of switching to natural gas. In countries, where natural gas is already a low cost fuel, the environmental benefit is a bonus and is not a subject for much analysis, but in countries where its cost is higher than an alternative fuel, then that extra cost may be worth paying for, if it can be shown that the community gains an equivalent overall benefit from the consequential reduced levels of environmental damage. That is an important equality for government policy makers to consider, for it adds an additional factor to the equation of optimum fuel mix, which, for the long term, can steer a government towards different approaches in energy pricing and can, in the short term, give confidence to a government introducing regulations which hasten changes in fuel use.

4.2 Costs of Air Pollution Damage

What are the costs of damage from air pollution from energy use and how easily can avoidance of environmental damage be equated to the use of one fuel or another?

Surprisingly, that question is difficult to answer. There is remarkably little data to link the amount of air pollutants emitted from an energy consuming source to the cost of the actual damage that it causes. The words are spoken about cause and effect, but the extent of consequential damage in economic terms is not well defined. In poorer countries, environmental damage from energy use is compounded often with more prominent factors related to poverty, a heritage of industrial pollution and service industry problems.

Even amongst the industrialized countries, there are only a few which have researched into a reasonably complete equation of the economic cost of air pollution control against the economic gains to be made in reduced damage (that damage to include value judgment on all related matters including loss of amenities). For those few countries in the world with good data, the correlation between source and damage is rarely clear-cut and the economic quantification of damage is well recognized to be subject to divergent and local value judgments. In developing countries it is suggested that much more work needs to be done to define the more important special factors in this equation for the specific country concerned.

Without local country data, developing countries are generally advised to be guided by more experienced countries, and aim their pollution control legislation towards specific concentrations of pollutants in the exhaust gases and specific pollutant emission rates. The test of success of this policy is whether air quality standards (such as those recommended by the World Health Organization) are achieved and maintained. The ultimate test of success is whether environmental damage is reduced to levels which the community in the long term judges to be acceptable.

4.3 Analysis of Environmental Benefits from the Use of Natural Gas

To paint the picture a little more clearly, it is useful to think through two recent cases of countries in which the World Bank has helped in assessing the environmental benefits of increased natural gas use. In both cases, the work was part of a technical and financial assistance program for the governments concerned to help prioritize their investment in new gas supply systems.

In one case, South Korea, the study analyzed the changes in pollutant emissions from replacing coal and firewood by natural gas and low sulphur fuel oil. The agreed plan to extend the import of natural gas as Liquefied Natural Gas (LNG) infers the price for natural gas that the urban communities were willing to pay for their improved urban air quality.

In another case, Poland, the study went into much greater depth in evaluating the environmental benefit of using natural gas in certain markets, to be able to advise on ranking the timing and direction of an investment program in natural gas.

However before these two cases are described and to set the scene, it is instructive to look back and consider, in the light of the passage of 35 years, the story of the British Clean Air Act of 1956 and the role which natural gas eventually played in helping to solve the major air pollution problems of the city of London.

Case Study 1. London

Peter Brimblecombe's book "The Big Smoke" provides fascinating reading of the history of air pollution in London. It is a story of a developing city, with its history of changing fuels, changing industry, increasing population density and increasing prosperity. Wood fuels were always used, charcoal was used increasingly as a "smokeless" industrial fuel, and coal became the major fuel in the nineteenth century.

It is the history of the London smog. The peculiar weather pattern over the Thames River Basin ensured that, on special days, the smoke from the chimneys of industry and home fires did not disperse but was contained over London. In cold winter days, when every home's open grates burnt coal, the sulphurous smoke from London's chimneys mixed with the natural fog to give extremely low visibility and a choking air. Novels written at that time made the smog of Victorian London famous.

Analyses of the smogs, as recorded by the measuring technologies available then, show frighteningly high figures. The major smogs were especially bad. They were the events that lasted several days and caused a recognizable increase in deaths by several hundred. The air quality was appallingly bad by the standards of today. The worst came in November 1952, when a particularly thick smog settled over London and lasted for five days. In the middle of one day the light from the sun was so obscured that the light intensity at street level was measured as 0.01% of the light intensity of a normal winter's day. Particulate concentrations exceeded a 24 hour average of *4,000 $\mu g/m^3$*, which is over *ten times* standard of the EC today for 24 hour air quality . SO_2 emissions peaked at *3,700 $\mu g/m^3$*. Those were the days when air pollution really was air pollution, at levels that are almost unimaginable by the new generations of the industrial world. The total amount of smoke emissions into the London air in 1953 was estimated at *2.5 million tons*, of which over half came from residential coal grates. "The Great Smog" of 1952 was attributed to be the cause of *4,000 deaths* that winter.

The consequence of the strong public and political reaction to the 1952 smog was the British Clean Air Act of 1956. The most important provisions of the Act were to:

- establish smoke emission standards for all emission sources
- require filters to be fitted to the larger industrial plants burning coal
- introduce smokeless zones and give grants for the conversion to smokeless fuels
- make new industrial plants use the best available technology for smoke emission control

The cost of the change was high and depended on the availability and cost of introducing smokeless fuels instead of coal. The expectation then was that the least-cost solution would be to produce smokeless fuels from coal and that domestic coke fuel would be the major fuel for the future. Coke production had its own pollution problems and to some extent the solution moved the source of pollution from the domestic grate to the industrial coke plant. As it turned out, while coke fuels found an increased market as a result of the Clean Air Act, they were shortly to be replaced by low cost oil and then by natural gas. As a result, it can be said that *the cost of the change was lower than the initial willingness to pay* that was implied by the Act. By the end of the1950's, the lower cost fuel oil was available, and coal-based gas also started to be replaced by cheaper oil-based gas. Natural gas, as LNG, was imported from Algeria, starting in 1964 and then in a major conversion program, starting in 1967, natural gas became available to consumers from the newly discovered gas fields in the UK North Sea.

With the lower prices and increased availability of fuel oil and natural gas, and with the passing of the Clean Air Act, the air quality over London improved dramatically. By 1972, twenty years after the great smog of 1952, smoke emissions had fallen by a factor of four, from 2.5 million tons to 0.6 million tons per year, and the number of days per year, on which the activities of London were significantly affected by smog, fell from 45 to 5.

The Clean Air Act of 1956 was aimed specifically at controlling smoke emissions and did not directly legislate against SO_2 emissions, even though SO_2 was a leading pollutant contributing to the environmental problems in London. However by reducing smoke emissions, the Government, and the Local Authorities which implementing the Act, effected a reduction in SO_2. In this respect, the replacement of coal-based fuels by fuel oil, gave immediate relief to the particulate emission problem, but as the intensity of fuel use continued to grow in the city, the SO_2 problem was not solved. It was then necessary to impose restrictions on the sulphur content of fuel oils, and a combination of smokeless coke fuels, low-sulphur fuel oil and of natural gas was able eventually to contain the problem. Natural gas became the major fuel for residential heating, as a result of three factors: the relatively high cost of producing smokeless fuels from coal, an aggressive marketing program by the Government controlled Gas Council and the availability of natural gas from the North Sea.

The most recent data for air quality over London show annual average concentrations of SO_2 to be 55 $\mu g/m^3$.

Although the British Clean Air Act was passed without reference to the concerns over greenhouse gases -- concerns that would emerge in strength some thirty years later -- the consequences of the Act were that natural gas largely replaced coal-based fuels. For that sector of the UK energy market, this effectively reduced CO_2 emissions, per unit of useful energy, by as much as a factor of three.

The UK nowadays consumes 55 Bcm of natural gas per year, representing 20% of its total energy consumption

Case Study 2. Korea

One of the key objectives of the plan of the South Korean Government to import more LNG is to reduce air pollution in urban and industrialized areas. Natural gas, which is free of most of the pollutants present in liquid and solid fuels, and generates less CO_2, is destined therefore to play an increasingly important role in South Korea's emission control strategies.

A comparison of Korea with other industrialized countries now shows that the level of urban air pollution is high, with SO_2 and total suspended particulates (TSP) being the most serious pollutants. Concentrations of carbon monoxide (CO) are also high in residential areas where anthracite briquettes continue to be used. Korea made progress some time ago by moving away from a reliance on local firewood and increasing the importation of coal and oil, but, as energy consumption continued to rise, the sulphur contained in these fuels led to an increasing problem from the SO_2 emitted to the atmosphere. Regulations, introduced in 1981 to lower the sulphur concentrations in heavy fuel oil, succeeded in reducing SO_2 emissions. The levels of SO_2 in the air over the large cities decreased immediately, but not to a sufficient extent, so that today, the concentrations of SO_2 still exceed the prescribed annual air quality standards of 110 $\mu g/m^3$. The average annual level of SO_2 over Seoul, for example, dropped from 220 $\mu g/m^3$ in 1980 (which made Seoul then to be the fourth highest SO_2 polluted city in the UNEP lists) to about 130 $\mu g/m^3$ in 1982, but has stayed at around that level ever since. Winter seasons see much higher average monthly levels, at around 300 $\mu g/m^3$.

TSP emissions also remain high. Average annual TSP concentrations over Seoul were about 200 $\mu g/m^3$ in 1985, reducing to about 150 $\mu g/m^3$ in 1989, but still are greater than the targeted prescribed level of 100 $\mu g/m^3$.

The South Korean Government is committed to curbing the deterioration of the environment caused by these air pollutants. A main policy, in an urgent response, is one of fuel allocation, involving regulations that specify minimum fuel qualities or barring altogether the use of certain fuels in specific areas or specific applications. To accelerate SO_2 control, the major oil refineries in South Korea are constructing new desulphurization facilities that will allow them to supply fuel oils with a much lower sulphur content. By 1993, when the program is complete, it will be possible for the Government to reduce the permissible sulphur limit of heavy fuel oil from 1.6% to 1.0% (it was 4.0% in 1980), and of light oils from 0.4% to 0.2%. Imported steam coal will remain at similar low sulphur levels of about 0.7% (i.e. 1% sulphur on an oil equivalent basis). The expectation of the people in the South Korean Ministry of the Environment is that they will be able to achieve the air quality target of being below 110 $\mu g/m^3$ for SO_2 in 1993. If the increase in fuel consumption in South Korea grows as fast as presently forecasted though, then this success will be rather short lived and it will be necessary to plan for additional controls in the coming years. A careful choice of the various options has to be made, and decisions made on the extent of natural gas in the long term fuel supply mix.

Power Sector and Large Scale Industrial Energy Users

For large scale boilers, there are a number of control technologies that are available to South Korea to reduce atmospheric emissions, from coal and oil firing, to levels that suit the environmental characteristics of the location. Least cost analysis can determine which combinations of fuel quality, fuel price, and user technology are best to achieve the required regional targets for air quality. Natural gas can be shown to be a preferred fuel for power generation because of the lower capital costs together with the higher thermal efficiency that are available in new combined-cycle gas-fired power plant, as well as the benefits of low pollution emissions. This can be the case even where the cost of gas supply is relatively high as is the case with sourcing it from imported LNG.

For power generation, South Korea plans on a strategic move away from a reliance on oil where possible, while increasing the use of low–sulphur coal, natural gas, and nuclear fuels. Natural gas will be a significant component in its fuel supply mix. Current plans are to import LNG at a level where it will provide 10% of the energy demand for electricity generation by the year 2010.

Smaller Scale Energy Users

For a number of fuel-users that are smaller in scale than electricity generation, natural gas from LNG can be expensive when compared with alternative available fuels. The cost of pollution control for small scale plants burning coal or high sulphur fuel oils can become unacceptably high. This is especially so when strict legislation is introduced to control pollutant emissions. Then, very low sulphur fuel oils, LPG, natural gas, and electricity can become economically preferred. In urban environments, natural gas has distinct advantages in this respect and the South Korean Government has decided to hasten the change to this fuel in urban residential and small scale fuel markets. A decree issued in 1990 by the Minister of the Environment will require residential apartments of above certain size to use only natural gas as a space heating fuel, with a designated timetable for change constrained within a period of the next three years. It is first being applied to Seoul, and then to a further fourteen metropolitan areas throughout South Korea. By 2010, the plans are for the residential and commercial markets to consume 6.5 Bcm of natural gas annually, which will be about 20% of the primary fuel consumed in that market sector. By then, South Korea will consume 16.2 Bcm of natural gas annually.

Calculation of Pollution Emissions

The Korean Energy Economics Institute (KEEI)Data has made estimates on the energy used in Korea for the year 2010 and these can be compred with use in 1989. Broad estimates of the changes over the next twenty years in the pollution loading of the atmosphere can be derived using appropriate factors for combustion emissions. This calculation though does not immediately predict the atmospheric concentrations of the various pollutants. That depends strongly on the intensity of the source locations and the regional climatic conditions. However it does indicate the overall size of possible forthcoming problems and gives useful indicators for the focus of future controls.

Using the KEEI data, estimates of the potential pollution emissions in South Korea have been calculated and are summarized in Table 4.1 for 1989 and Table 4.2 for 2010.

Table 4.1 Fuel Combustion Emissions - Korea 1989
(million tons)

Fuel	Energy Used	Emissions				
	(PJ)	SO_2	TSP	NO_x	CO	CO_2
Firewood	43		0.05	0.01	0.09	5
Hard Coal	1,029	0.42	0.15	0.28	1.19	96
Natural Gas	110 *			0.02		6
Liquid Fuels	1,446	0.33	0.04	0.49	0.71	106
Nuclear	497					
Hydro	48					
Others	22					
Total	3,195	0.75	0.24	0.80	1.99	213

* 110 PJ = 2.6 million toe = 3.1 Bcm natural gas

Table 4.2 Fuel Combustion Emissions - Korea 2010
(million tons)

Fuel	Energy Used	Emissions				
	(PJ)	SO_2	TSP	NO_x	CO	CO_2
Firewood	20		0.02	0.01	0.04	2
Hard Coal	1,804	0.59	0.11	0.53	0.56	170
Natural Gas	572 *			0.06		31
Liquid Fuels	3,926	0.63	0.12	1.48	2.18	292
Nuclear	1,358					
Hydro	38					
Others	105					
Total	7,823	1.22	0.25	2.07	2.78	495

* 572 PJ = 13.6 million toe = 16.2 Bcm natural gas

The fuel qualities and emission factors used in these calculations are average factors estimated for Korean fuel utilization. The emission factors take into account the installation of particulate emission control from power and large scale industrial plants that burn coal, and of flue gas desulphurization in power plants that burn coal or oil. All other factors assume uncontrolled emissions of standard combustion technology. Both the 2010 data and the 1989 data assume the same emission factors. With new technology and with better emission control equipment, emissions will decrease, but this development has not been included in the calculations to permit a clearer view of the policy options open to Korea.

Reduced Pollution Emissions from Using Natural Gas

Two broad changes to the pollution emissions relate to the use of natural gas in Korea. The changes are interwoven with the increased use of low sulfur fuel oil that will happen at the same time, and it is not possible to segregate the two. Both are part of the continuing move away from extensive use of anthracite briquettes and firewood.

First, as much as 380 PJ (13 million tons coal equivalent) per year of anthracite briquettes and firewood will be taken out of the residential and commercial markets. As a result, the TSP emissions will be lowered by an estimated 0.1 million tons per year, and the CO emissions lowered by 0.9 million tons per year. Both amounts represent a substantial 80% reduction in the current pollution loading from these sectors.

Second, taking the total amount of coal, including the anthracite, which will be effectively displaced from all market sectors, then the increased use of natural gas and low sulfur fuel oils can be shown to eliminate the production, every year, of about 0.3 million tons of SO_2 and about 30 million tons of CO_2. These figures are 25% and 6% respectively of the expected emissions from all sectors in 2010.

Natural gas contributes towards these improvements in the future air quality of Korean cities. The substantial reductions in TSP and CO especially, can be credited to the anticipated improvements in the health of urban populations.

Costs of Natural Gas Supply

An economic evaluation of the plans to increase the extent of use of natural gas in Korea, has to incorporate the investments in the LNG import terminals, in the gas transmission lines to the power stations and in the city gas companies, together with the investment in the gas distribution systems within the cities. The economic costs therefore include the CIF price of imported LNG as well as the capital and operating expenditures incurred by the transmission and distribution companies. Netback values of the gas for the power sector are based on a comparison of gas-fueled generation with the most likely coal-fired alternative. The result of this evaluation establishes that the investments are commercially acceptable with LNG CIF prices of the international trade that Table 2.7 quoted earlier as being typically \$3.5/mmBtu.

The environmental benefits of gas are recognized, in this evaluation, in the higher thermal efficiency of the gas-fired plant and the lower costs of pollution emission control inherent in gas-fired power generation as compared with coal. The cost of supply of natural gas to the smaller industrial, commercial and residential customer is higher of course, and will be covered by higher prices offered to those consumers. Where the new restrictions in the cities force customers to use gas in preference to oil and coal, the extra price reflects effectively, the willingness of the community (of which the individual customer is only a part) to pay for lower levels of air pollution. Details of those price schedules are not available but suffice it to say, that they are palatable, still based on the $3.5/mmBtu price structure for sourcing the gas.

From this can be inferred that the South Korean government places a high value on natural gas. The Japanese have held those views for some time: they have installed very strict controls on pollutant emissions and have proved over the past twenty years that imported LNG is commercially competitive with other energy sources and have long established LNG as a key player in support of environmental policies.

Case Study 3. Poland

Poland is in the midst of a major program of internal reform designed to address the country's severe economic problems. The energy sector is one of the largest sectors in the Polish economy and is a major focus of attention. Within the overall energy restructuring program, a high priority has been placed on the preparation of a Gas Development Plan.

Poland faces severe problems from air, soil and water pollution. A Government study in 1983 led to 27 areas of Poland being officially designated as "areas of ecological hazard". Together, these areas constitute approximately 11% of the total area of the country and have nearly 13 million inhabitants -- 35% of the total population. The areas of Upper Silesia, Rybnik and Krakow have especially severe problems associated with heavy industry and over-exploitation of coal resources, compounded by congested urban development.

Many of Poland's environmental problems result from energy supply and use. Use of coal in power generation, district heating, home cooking and heating, and coke production generates great quantities of particulates (TSP) and gaseous pollutants. Energy supply and use account for virtually all emissions of SO_2, NO_x, TSP and CO_2 in Poland. Coal is the source of between two thirds of the emissions of TSP, three quarters of the emission of SO_2, a third of the NO_x emissions and over a half of the emissions of CO_2.

The effects of these emissions are diverse and include damage to buildings and structures, damage to human health, destruction of forests, loss of agricultural production and loss of heritage. The seriousness of the situation and the precise role of emissions in causing these types of damage is unclear, in part due to a lack of systematic measurement of biophysical changes and their economic and human health consequences.

Ambient air concentrations of SO_2 in parts of Krakow exceed 100 $\mu g/m^3$ as an annual average, rising to 150 $\mu g/m^3$ during the winter heating season. Average TSP concentrations in the heating season exceed 150 $\mu g/m^3$, with peak levels reaching 500 $\mu g/m^3$. In Upper Silesia, the town of Chrzanow sees annual average concentrations of TSP of 300 $\mu g/m^3$. WHO guidelines recommend annual average exposures below 40-60 $\mu g/m^3$ for SO_2 and below 60-90 $\mu g/m^3$ for TSP.

In the heavily polluted region of Upper Silesia the incidence of congenital diseases, cancer and chronic bronchitis is very high. Causes include various types of pollution, including smoking, diet and other sociological factors. Some dietary factors are indirectly linked to air pollution since toxic elements including heavy metals accumulate in the soil and contaminate the food. However it is not possible to establish the relationship between the occurrence of health problems and environmental factors, let alone individual pollutants.

Evidence exists which links air pollution from energy use with other types of damage. Many historic buildings and monuments in the city of Krakow are soiled and corroded as a result of air pollution. Ambient concentrations of SO_2 are well above the level at which harmful effects to stonework are likely to occur. In some regions of Poland, sulphur deposition exceeds 1000 ton/sq. km per year, exceeding, by 3 or 4 orders of magnitude, the levels at which harmful effects to forests, soils and lakes are likely to occur.

The Role of Natural Gas in Poland

The Polish Government's planned initiatives towards increased production and use of natural gas, in part, are directed towards helping to solve Poland's critical environmental problems, and in part aimed at making optimum economic use of Poland's own gas reserves. Poland's gas reserves are estimated at 175 Bcm, to which has now to be added Poland's substantial resource of coal-bed methane (see Section 2.4) which is placed between 380 Bcm and 1,300 Bcm. Poland now produces its own natural gas at a rate of 5 Bcm per year, which, combined with imports from the USSR of 8 Bcm per year to give a total consumption of 13 Bcm per year that contributes 9% of Poland's energy needs in 1989. Poland is heavily dependent on coal so that substitution of natural gas for coal in selected projects of power generation, industry and residential heating, if well integrated with other possible changes in industry and infrastructure, could realize substantial improvements in air quality.

A Gas Development Plan, conceived as one of three scenarios, would increase the percentage of natural gas used to 17%, while energy intensity decreases by 37% and economic growth is assumed as 5% per year. Calculations using the scenarios of this plan and the models developed by the Institute of Technological Research in Warsaw, show the consequences of the proposed change to decrease the total annual air pollution loads in Poland as shown by Table 4.3 for the year 1988 and Table 4.4 for 2010.

The High-Gas scenario underlying Table 4.4 is the lowest cost scenario of three scenarios that were explored and which could satisfy the national environmental targets of a 30% reduction in SO_2 by the year 2000 and a 50% reduction by 2010, and a 50% reduction in TSP emissions by 2000 and a 70% reduction by 2010, both compared with 1980 levels. The other two scenarios that would meet these targets include the more expensive options of nuclear power in one scenario and more coal-fired, flue gas cleaned, power stations, in the other. The High-Gas scenario implies a tripling of gas consumption by 2010 to 45.5 Bcm per year.

The estimates of emission reductions relate to average levels of emission for Poland as a whole. The situation will differ for individual locations. For example, in the case of Krakow town, estimates are that three quarters of the deposition of SO_2 originates from sources in or close to the town, the remainder originating from further afield, largely from Upper Silesia, but also from across the border in Czechoslovakia.

If Poland achieves its national target for SO_2 reduction of 30% by the year 2000, then the level of SO_2 deposition in Krakow would fall to perhaps 75% of recent levels. However the complete substitution of coal use in and around Krakow by natural gas could reduce deposition to as low as 20% of recent levels. Again, these assessments are for average rates. In practice, excursion episodes of very high concentrations and depositions, do occur, and are strongly associated with low-stack emissions. Substitution of natural gas for coal would have an even greater proportionate impact on the visual, and health consequences of these emissions.

Table 4.3 Fuel Combustion Emissions - Poland 1988
(million tons)

Fuel	Energy Used	Emissions			
	(PJ)	SO_2	TSP	NO_x	CO_2
Lignite	592	0.7	0.2	0.1	57
Hard Coal & Coke	3,548	2.7	1.6	0.51	294
Natural Gas	406 *			0.03	16
Liquid Fuels	740	0.2		0.55	47
Nuclear	0				
Others	100	0.2	0.3	0.16	46
Total	5,387	3.8	2.1	1.35	460

* 406 PJ = 9.7 million toe = 11.5 Bcm natural gas

Table 4.4. Fuel Combustion Emissions - Poland 2010 - High-Gas Scenario
(million tons)

Fuel	Energy Used	Emissions			
	(PJ)	SO_2	TSP	NO_x	CO_2
Lignite	440	0.1		0.1	41
Hard Coal	2,965	1.3	0.6	0.4	243
Natural Gas	1,610 *			0.2	81
Liquid Fuels	1,205	0.3		0.8	74
Nuclear	0				
Others	135	0.1	0.3	0.1	35
Total	6,355	1.8	0.9	1.6	474

* 1,610 PJ = 38.3 million toe = 45.5 Bcm natural gas

Environmental Value of Natural Gas

An aim of the environmental gas study for Poland was to attempt to establish an appropriate "environmental credit" for natural gas measured in monetary terms. The credit would be specific to the application that uses natural gas. It would therefore affect the relative "value in use" of natural gas among different applications, which potentially changes the priorities for allocation of natural gas within Poland.

The approach adopted followed recent work in OECD countries and laid emphasis on the establishment of critical loads for air pollution, below which no detectable damage occurs and above which incremental damage is treated as if it varies linearly with load. This assumption is not fully justified, because it implies that the marginal benefit of a reduction in pollution load is independent of the level of pollution, but it is a convenient one for analysis.

The benefit of a reduction in emissions from a particular source is assessed as the lesser of:

a) the cheapest alternative approach for achieving the same level of emissions reduction that would be achieved by gas substitution in that particular application, and

b) the monetary valuation of the benefit of reduced emissions caused by natural gas substitution.

Clearly, natural gas cannot be credited with the full value of b) if it is cheaper to reduce the emissions by another means, such as the installation of pollution abatement technology. Similarly, natural gas cannot be credited with the benefit of avoiding the cost of abating emissions from the source in question if the monetary value of the damage by emissions being abated is less.

The marginal value of changes in pollution level will be set by the lower of the marginal cost of abatement and the marginal damage caused. A direct comparison can be made then of the marginal cost of abating a ton of emission, on the one hand, and the value of marginal damage (in another location) related to the emissions from a particular source on the other. As guided by the experience of Western European countries, the setting of strict emission targets implies a willingness to pay for pollution abatement that is often higher than the cost of measurable environmental damage, which in turn implies a very high amenity value placed on environmental cleanliness. The marginal damage assessed in Poland was weighted accordingly.

The value of natural gas in reducing emissions will depend, in part, on the cost of achieving comparable emission reductions by other means. The cost will depend on the target levels of emission reduction, the more severe the reduction the higher the cost of the technical option to achieve it. For example, a SO_2 reduction of 15%, achieved principally by moving away from high sulphur lignite to high quality hard coal in power generation, would have an associated marginal abatement cost estimated at $600/ton of SO_2. A reduction of 30% in SO_2 however would require additional investment in flue gas desulphurization in the power stations, at a higher marginal abatement cost of $1100/ton of SO_2.

Since natural gas contains virtually no sulphur, the value of natural gas as a fuel in power stations can therefore be matched against the cost of using coal with the extra abatement costs. Emissions of TSP can be treated in the same way and the marginal emission abatement cost will similarly increase as the level of emissions of TSP is required to decrease. The environmental credit for a reduction in SO_2 and TSP, assignable in this way to the value of natural gas, as is the overall cost of pollution control, strongly depends on the severity of the emission reduction targets which the Polish Government sets for the longer term.

Table 4.5 shows a summary of the result of the analysis. Environmental credits are attributed to natural gas in the various broad end-use market sectors as a combination of reduced emissions of SO_2 and TSP.

Table 4.5 Estimates of Environmental Credits for Natural Gas in Poland

Market Sector	Credit ($/mmBtu)
Residential	3.5 - 5.0
Commercial	3.5 - 4.0
Industry - coal	3.5 - 4.0
- heavy fuel oil	1.0
Power & District Heating - existing, 2.3% S coal	1.5
- new, 1.2% S coal	0.2

These environmental credits are very dependent on two key policy decisions, one concerning abatement of TSP emissions from high stacks, the other concerning enforcing the use of smokeless fuel instead of coal in urban areas. It should also be emphasized that the environmental credits represent the benefit of displaced emissions *at the margin*. This is very appropriate for assessing the priorities to be adopted for allocation of natural gas and for marginal changes in the volume of gas consumption, but it is not valid to impute an overall environmental benefit of the gas development plan by multiplying the total volume of gas use by the marginal values of displaced emissions given in Table 4.5.

Allocation of Natural Gas Supply

The plans of the Polish Government include bringing the price of natural gas up to a level where it equates to mid-European border prices by 1993, which means establishing ex-transmission pipeline prices of around $2.5/mmBtu (reference Table 2.7). Those prices would be sufficient to support further investment in Poland's own natural gas production and to enlarge where possible imports from other sources including possibly Norway as well as the USSR. In the case of Poland, natural gas can displace coal and oil use on a competitive basis at such border prices without resorting to netting back the environmental credits tabled above to make the commercial justification.

What is useful in the Poland case is to incorporate the concept of environmental credits to justify choices made in priority allocation and investment in appropriately placed gas transmission and distribution networks. With marginal environmental credits estimated to be in about $1 to $5/mmBtu, several key markets can be seen to be of high priority for natural gas, that is being seen to be commercially sensible for the community at large. This valuation encourages, and can be used to justify, moves towards replacing coal by natural gas in urban areas especially.

The Government and local authorities in Poland are considering these changes at the moment. Poland is well aware that other countries have moved quickly on solving their air pollution problems by restricting coal burning and selecting certain markets for the lower polluting fuels. As witnessed by the case studies above, the UK enacted such laws in the 1950's and South Korea in the 1990's. The expectation is that Poland will move soon in a similar direction.

5. Future Trends and Issues

Natural gas presents opportunities that are highly significant for the future energy policies of developing countries. This paper has attempted to summarize the building blocks of technical and economic opportunity on which to establish those policies. It has pursued several main themes.

First was the ***encouraging resource position*** where, as a rule, there are substantial reserves of natural gas in developing countries. The future will undoubtedly see more of these reserves being used, and more reserves discovered as more commercial opportunities for natural gas become established. Marginal costs, again as a rule, appear to be sufficient, provided that the industry develops a sufficiently large market for the gas. While there are vast amounts of "unconventional" reserves of natural gas, their costs are generally too high, with the one exception of coalbed methane that will be used in small but increasingly significant volumes in some countries.

Second was the ***availability of large scale, highly efficient, gas-fired power generation technology,*** which for reasons of lower capital cost and higher speed of construction is attracting a new wave of investment in the electricity industry of developing countries, For those countries that have a natural gas resource, but have yet to exploit it, the development of a gas-fired power station project can provide the commercially justified starting point for the development of a widespread gas industry. The experience of other countries has shown that, above a certain critical size, the natural gas market can expand quite readily into industry, commercial and residential sectors in a satisfactory way.

Third was the ***environmental benefit*** of natural gas. While, in competition with other fuels such as coal, natural gas can be the more expensive fuel on thermal value alone, it can be credited justifiably, with additional economic values, because of its benefits to the environment. Communities suffering from, or even those communities wise enough to anticipate, the problems of severe air pollution, are willing to pay an environmental premium for a clean fuel. If that premium is high, it may be enough to cover the extra costs of transmitting the gas from the production well or the extra costs of extending a gas distribution system into a city. This happened in the past, as in the case of London, and in more recent times in several other countries including the case considered here of South Korea. In the detailed analysis of the case study of Poland, the environmental credit for natural gas was assessed as being substantial, being at least several $/mmBtu, and being of the same order as the cost of supply. The environmental credit for a clean fuel and related energy policy decisions by governments, are so dependent on the targets agreed on for air quality and for emission standards. The consequences of international advice on emission standards for developing countries have to be thought through quite carefully in this regard.

The question of the real cost of ***environmental damage*** from air pollution needs further research. There is insufficient data on the value of environmental damage in developing countries. More often pollution is described as "bad" without reference to the actual extent of the economic damage to the community. The case studies described in this paper paint a picture in which environmental value judgments, as well as least-cost technical solutions, are guiding the price at which communities are willing to pay for clean fuels like natural gas. Those value judgements obviously will vary from one country to another. It is suggested that governments of developing countries would be helped by methodologies, which take local environmental damage more into account in economic terms and which include local as well as international value judgments on clean environments. It seems to be important that these issues are recognised and debated in guiding a choice of energy investment policies.

As to ***global environmental issues***, natural gas is now well recognized as having a strong role in future energy policies towards helping to reduce emissions of greenhouse gases. Clearly, natural gas can easily halve the emissions of CO_2 compared to coal-based fuels for the same amount of useful energy. Developing countries, with natural gas, can thereby increase their energy consumption as part of an economic development program, with less global loading of CO_2. Developing countries, which place natural gas highly on their energy policy agenda, will find that the international development agencies are increasingly able to support investment in natural gas, as part of an international program aimed at partly solving the global warming problem.

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