NAVAL POSTGRADUATE SCHOOL
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THESIS

AN ASSESSMENT OF THE ROLE OF COAL IN THE LONG-TERM ENERGY PLAN FOR KOREA

by

Jin Seob Cha

March 1982

Thesis Advisor: D. Whipple

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Evaluation of this impact in the long term is approached by studying five issues. These are: (1) Description of energy consumption sectors in Korea; (2) Description of energy resources/production in Korea; (3) Description of energy resource imports in Korea; (4) Description of long-term energy requirements in Korea; and (5) Conclusions and recommendations.

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An Assessment of the Role of Coal in the Long-Term Energy Plan for Korea

by

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Major, The Korean Army
B.S., The Korean Military Academy, 1974

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requirements for the degree of

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March 1982

ABSTRACT

During the last two decades, Korean industry has been developed very quickly. Energy consumption also has been increased very rapidly by the growth of industry. These energy requirements should be imported from other countries because Korea has few energy sources. Korean energy consumption depends highly on oil, even though oil has less security of supply and a higher price than other energy sources due to the limitation of oil reserves and the oil cartel. The Korean government wishes to import energy sources with more security of supply and a lower price.

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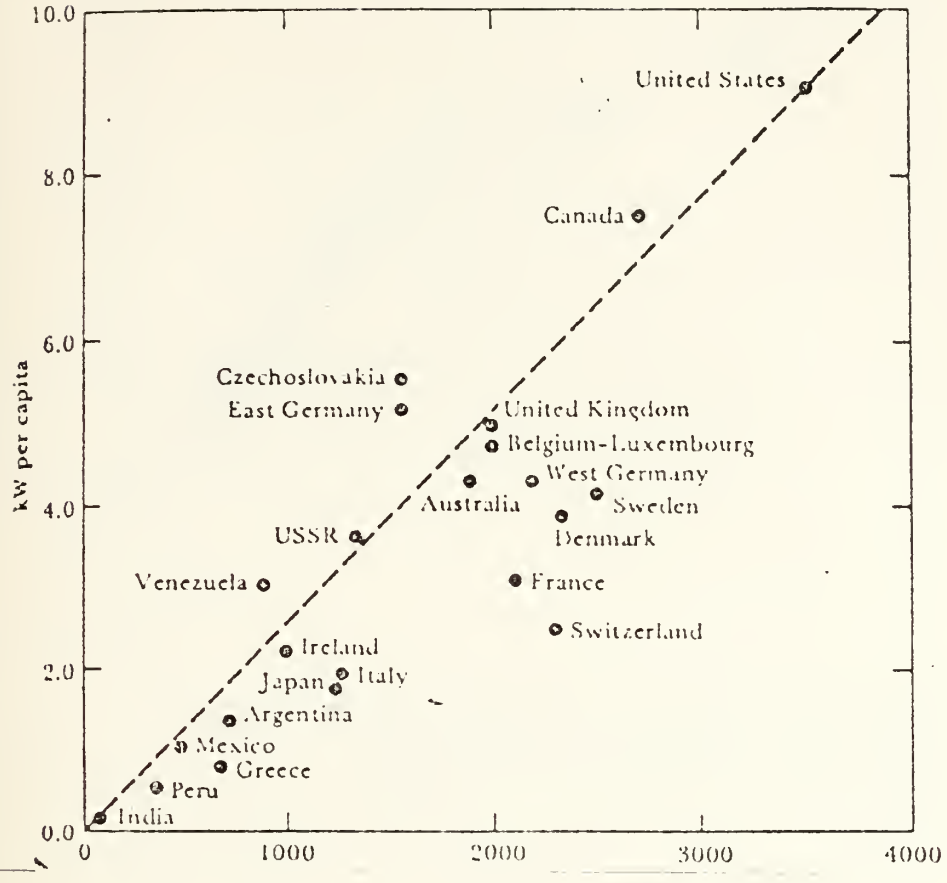
I. ENERGY CONSUMPTION IN KOREA

A. OVERVIEW

While the world population has been increasing at a rate of approximately 2 percent per year, energy consumption sustained the higher growth rate of 5 percent per year during the past several decades. Both a higher quality of life and an increasing gross national product appear to be related to an escalating rate of energy consumption as seen in Figure 1. Included in the graph are the ten countries with the highest per capita energy consumption, as well as several other countries for perspective. The dotted line represents a curve which is fit based on minimizing the mean square error.

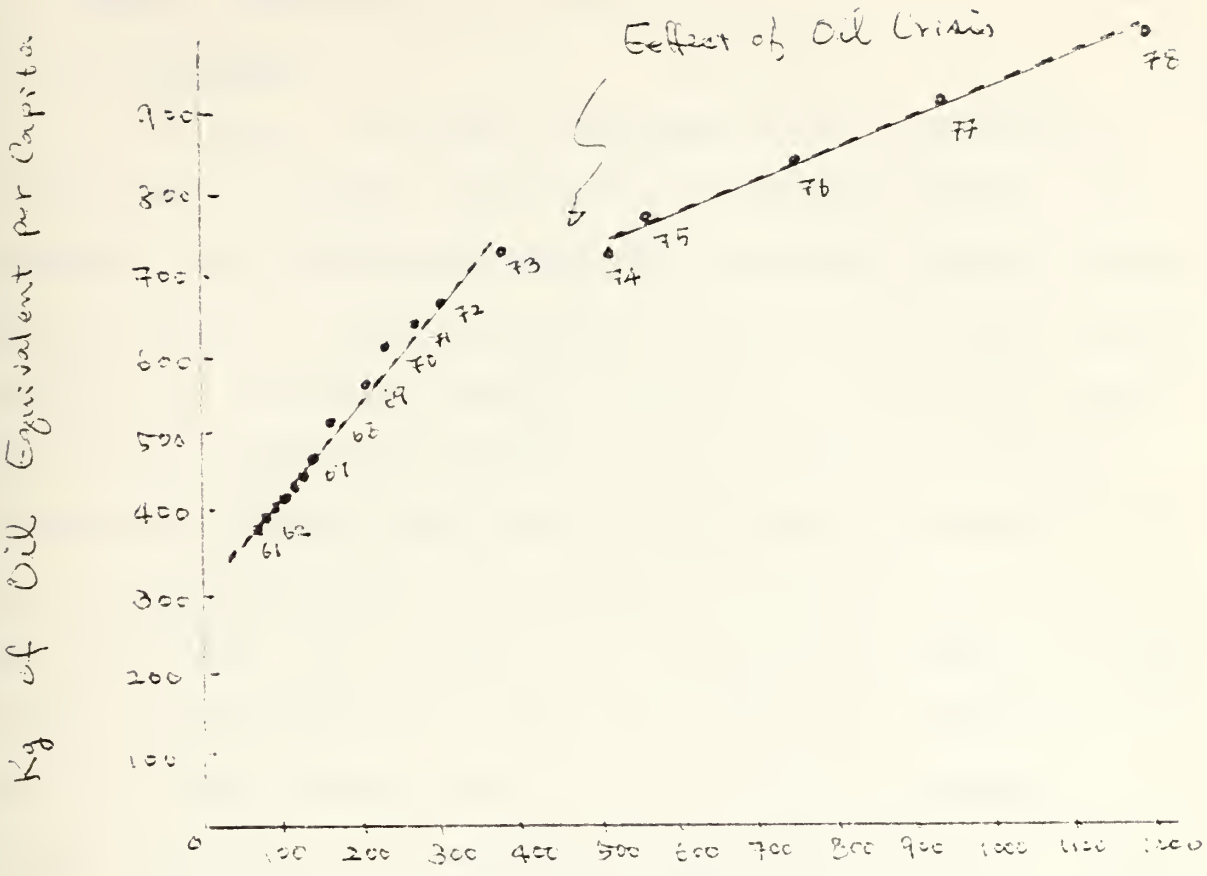
In interesting contrast, the energy consumption of Korea increased about 8.5 percent per year between 1961 and 1978. In the year 1961, the energy consumption of Korea was 9.8 million tons of oil equivalent (MTOE). By 1978, it had increased to 36.2 MTOE. The increase in the energy consumption rate remained high except during the oil crisis in 1973 as seen by the break point in Figure 2. The two dotted lines represent the least square lines for before and after the oil crisis. Annual total energy consumption data from the year 1961 to 1978 will be presented and discussed in Chapter IV.



GNP (U.S. dollars) per capita

Source: Jerrold H. Krenz, Energy, November 1977, page 5. [Ref. 1]

Figure 1. 1965 Per Capita Energy Consumption vs. Per Capita GNP



Source: "The Comprehensive Plan for Energy Supply-Demand to the Year 2000 (1978), Ministry of Energy and Natural Resources in Korea," p. 154. All subsequent references to this document will be referred to as "Comprehensive Plan," p. ___. [Ref. 3]

Figure 2. Per Capital Energy Consumption vs. Per Capita GNP (1961 - 1978) in Korea

B. ENERGY CONSUMPTION BY SECTOR

1. General

In 1961, the energy consumption of the industrial sector was 44 percent; the home and commercial sector, 42 percent; the transportation sector, 6 percent; and the others were 8 percent. During the past 15 years, the energy consumption of the industrial sector increased 12 percent per year, the energy consumption of the home and commercial sector increased 7 percent per year, and the energy consumption of the transportation sector increased 20 percent, on the average, per year. As a result, the proportional energy consumption of the industrial, home and commercial, transportation, and the other sectors, were 39, 35, 15, and 10 percent respectively of the total energy consumption in 1977. During the oil crisis, the energy consumption of the industrial sector increased because of government assistance to sustain the high industrial growth. The other sectors decreased during this period.

The details of energy consumption by sector will be presented in Chapter IV. The percentages of annual energy consumption are summarized in Figure 3.

2. Industrial Sector

In 1961, the energy consumption of the industrial sector was 4.3 MTOE. Except for the beginning of the 1960's, it increased steadily by about 12 percent per annum and reached 12.98 MTOE or 39 percent of the annual total energy consumption,

Year	Industry	Home and Commerce	Transpor-tation	The Others	Total
1962	-18.0	30.4	- 2.2	19.9	6.3
1963	-28.5	28.5	- 9.6	10.9	5.4
1964	13.5	3.4	-11.4	- 0.5	4.6
1965	10.2	0.8	43.8	- 1.9	4.7
1966	12.9	2.4	42.3	8.2	7.9
1967	12.1	1.4	35.9	-17.8	5.2
1968	15.6	8.1	33.3	- 6.9	11.7
1969	15.7	6.7	16.1	47.4	12.9
1970	9.2	11.3	13.6	57.8	14.3
1971	10.2	2.0	16.5	23.7	8.4
1972	4.2	1.6	5.2	11.0	3.9
1973	25.4	6.1	24.8	7.3	14.5
1974	8.2	-2.0	- 5.4	- 2.3	0.9
1975	15.1	1.4	- 3.6	6.4	6.2
1976	10.8	7.6	24.8	0.0	10.1
1977	12.3	7.5	19.6	10.9	11.3
Avg	8.05	7.32	15.23	10.88	8.01

Source: "Comprehensive Plan," p. 164. [Ref. 3]

Figure 3. Percent Change of Annual Energy Consumption by Sector

in 1977. During the oil crisis, the energy consumption of the industrial sector continued to increase because of government support provided to maintain the high industrial growth rate.

The energy consumption of the mining element of the industrial sector was established, to a large extent, by charcoal at the beginning of 1960, coal in the middle of 1960, and oil after 1970. By decreasing the coal and charcoal usage, the consumption of electric power energy relatively increased.

The energy consumption of the other parts of the industrial sector such as construction and steel production required coal and charcoal before 1965 and shifted to coal and electric power after 1965.

In 1977, the oil utilization of the industrial energy consumption sector was 75.0 percent. .

3. Home and Commercial Sectors

The energy consumption of the home and commercial sector was 4.06 MTOE in 1961. It increased to 42 percent of the annual total energy consumption at the beginning of the 1960's. The increasing rate slumped after 1964, so that the energy consumption of the home and commercial sector was twice that of the industrial sector until the middle 1960's. After 1974 the industrial sector consumed more energy than the home and commercial sector because of government support. The energy consumption reached 11.9 MTOE, or 35 percent of total energy consumption in 1977. The decrease from 42 percent to 35 percent was caused by increased in the other sectors.

The energy consumption of home and commercial depended mostly on charcoal before 1970, but shifted to coal after 1970.

4. Transportation Sector

In 1961, the energy consumption of the transportation sector was 0.6 MTOE, or 6 percent of the total energy consumption. The transportation needs decreased at the beginning of the 1960's and also during the oil crisis, but it increased during all other periods.

The transportation sector consumed 4.8 MTOE in 1977, and the energy usage increased from 6 percent of the annual total energy consumption in 1961 to 15 percent in 1977. During the oil crisis, there was a more significant impact on the transportation sector than on the other sectors. This was due to the rapid increase of gas and diesel prices in the face of governmentally controlled nonincreasing industrial fuel prices.

The energy consumption of the transportation sector was highly influenced by oil availability. This oil dependency was 70 percent before 1965, and went to 95 percent after 1970.

C. ENERGY CONSUMPTION BY SOURCE

1. General

Coal was the major energy source in the world until the beginning of 1950, however, since 1960 petroleum has assumed that role. The annual rate of use of petroleum increased from 32.4 percent during 1957 to 474. percent just

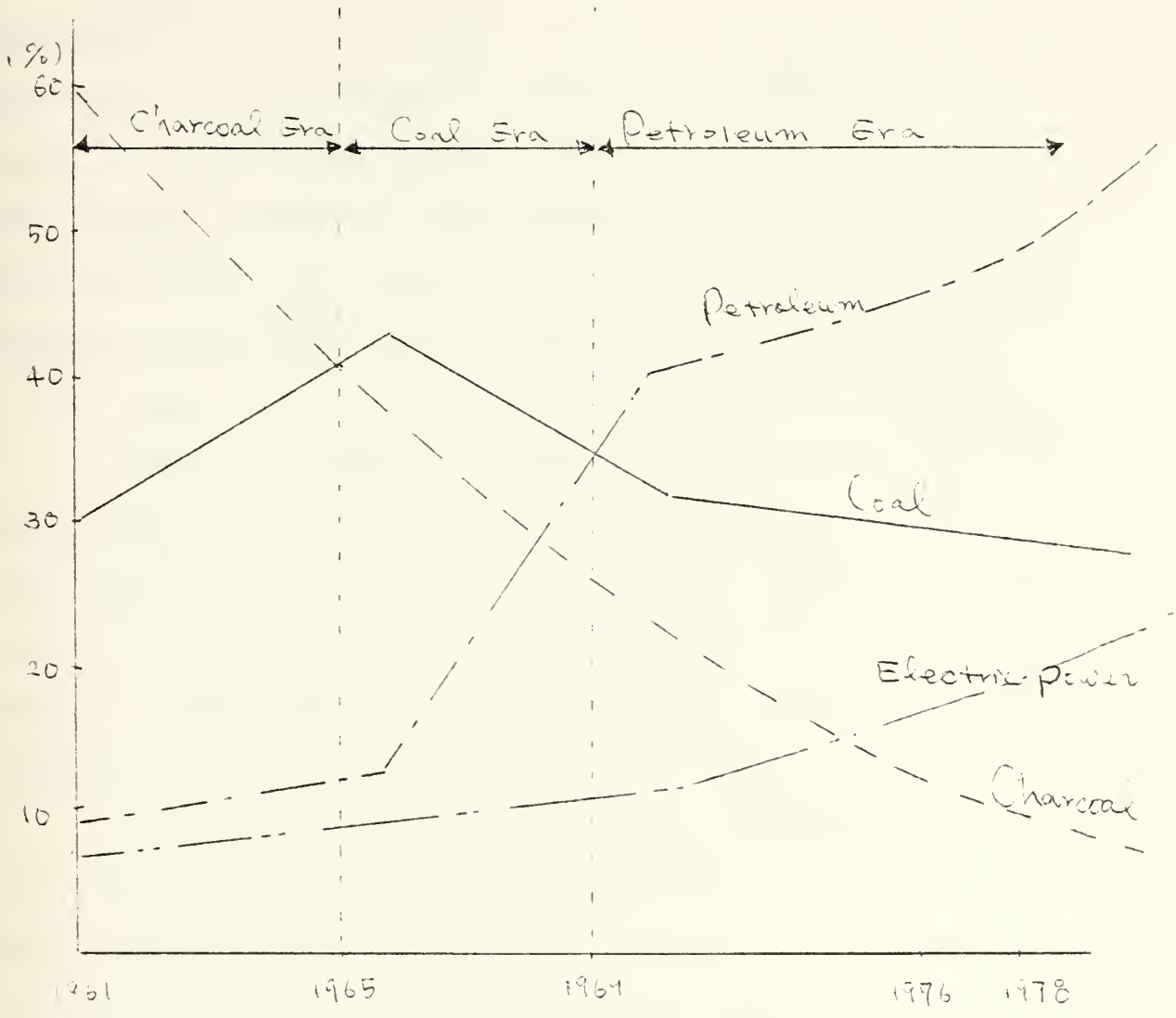
before the oil crisis occurred in 1973. Since then it has been stable at about 46 percent. Relative coal usage decreased from 52.2 percent per year during 1957 to 27.7 percent in 1973. The consumption rate of water power was stable after 1968. The consumption rate of nuclear power increased rapidly from 0.3 percent per year during 1968 to 2.3 percent in 1978. Although some nuclear power plant projects have been delayed due to perceived dangers of nuclear accidents, France, Japan, and Russia are planning to build new plants at a rapid rate.

On the other hand, in Korea, until 1965 coal and charcoal supplied 85 percent of the annual energy consumption. This usage decreased to 65 percent about 1969 and further decreased, and been stable at approximately 30 percent since 1970. The petroleum consumption rate has been increasing very rapidly. The rate of oil consumption was below 10 percent of the annual total energy consumption in 1961, but it is now abut approximately 60 percent (Figure 4).

2. Charcoal

Charcoal was the major energy source in Korea until the beginning of 1960. Charcoal was used for residential cooking and heating. Charcoal consumption declined for three reasons:

1. Charcoal consumption by heavy industry declined.
2. Government policy limited charcoal production to prevent forest denudation.
3. House improvement switched from using charcoal to coal.



Source: "Comprehensive Plan," p. 172. [Ref. 3]

Figure 4. Energy Consumption Pattern

In 1961, the charcoal consumption was 5,636 thousand tons of oil equivalent which was 57.1 percent of the total energy consumed. In 1970, it dropped to 4,251 thousand tons of oil equivalent or 21.5 percent of the total energy consumption. And in 1978, it was 3.04 MTOE, or only 8.4 percent of the total energy utilized. The quantity of charcoal consumed declined slowly, but the proportion decreased sharply. The consumption of other energy sources increased sharply.

3. Coal

The coal consumption centers are located largely in the northeast. Coal consumption increased before 1966, but since then it has accounted for a steadily declining percentage of energy consumption in Korea. In 1966, coal met 46.5 percent of total energy requirements. By 1970, coal had declined to 30.4 percent. It fell to 27.1 percent in 1978.

All coal consumption was either bituminous or anthracite. In 1978, bituminous coal accounted for 15 percent of coal consumption and in 1979, 24.5 percent. All bituminous coal was consumed in the industrial and electric power sectors.

The residential and commercial sectors are the heaviest users of anthracite, accounting for 68.1 percent of coal consumption in 1965, 86.2 percent in 1971, and up to 90.8 percent in 1978.

The most important uses of anthracite in the residential and commercial sectors are for home cooking and heating; in fact, coal briquettes for these uses account for 90 percent of all urban household fuel consumption.

Briquette consumption has continued to increase as population and incomes increase, and coal is substituted for declining supplies of firewood. Anthracite is a particularly convenient fuel for the Korean cooking and heating system.

The share consumed for electric power generation dropped sharply from 15 percent in 1965 to 5.2 percent in 1971. The decline has been slower since 1971. In 1978, the electric power industry used 4.5 percent of the anthracite consumed. Industrial consumption, which accounted for 5.3 percent in 1971, fell to 3.5 percent in 1978. Transportation and other uses, which accounted for 2.7 percent of consumption in 1971, required only 1.2 percent in 1978.

4. Petroleum

In 1961, oil consumption was 0.79 million tons which was 8.0 percent of Korea's total energy requirements. In 1970, it increased to 9.18 million tons, or 46.5 percent of total energy needs. The consumption rate has grown very rapidly with the development of the country's industrial base. In 1978, oil consumption was 22.14 million tons, or 61 percent of Korea's energy needs.

Oil consumption is highest in the industrial and electric utility sector. Bunker coal, which is used for steam raising, accounts for almost half of all consumption. Gasoline use is low, because of high gasoline taxes and low per capita vehicle ownership.

In 1977, residential users utilized about 4 percent of all the petroleum products moving through the Korean economy.

Of this amount, kerosene and diesel fuel accounted for more than half. The low level of residential use was due to the pervasiveness of the Korean heating and cooking system and the associated relatively low price of anthracite coal.

The industrial sector consumed about one-third of all petroleum products in 1977. More than half of this amount involved steam raising rather than applications requiring close temperature control and process heat. As a result, there may be some opportunity for switching to coal.

The transportation sector accounted for about one-sixth of all petroleum consumption in 1977. The low incidence of automobile use and the reliance on public transportation is evident in the breakdown of petroleum product uses: about 40 percent was for diesel fuel used in public vehicles, while only 16 percent is gasoline used for private vehicles.

Electric power generation consumed nearly one-fourth of the oil supplies. Most of this was heavy fuel oil, in addition to a small quantity of diesel fuel.

About 18 percent of petroleum products were used for miscellaneous purposes, such as 35 percent for military purposes, and the rest for international ships hunkering and other unidentified purposes.

5. Nuclear Energy

Nuclear power demands didn't begin until 1976. In 1977, it utilized 18 thousand tons of equivalent oil, or 0.05 percent of the total energy consumption. In 1978 it

increased to 581 thousand tons of equivalent oil, or 1.6 percent of all energy used.

The requirements for nuclear energy increased very rapidly because of the lack of energy reserves in Korea, the rapid increase of oil prices, and no other guarantee of a stable energy supply.

6. The Others

The use of hydroelectric energy increased from 0.16 MTOE in 1961 to 0.45 MTOE in 1978. The amount of usable water flow limited the development.

Korea does not currently consume natural gas, because there are no natural gas reserves or imports. Korea produces, for internal use, a gaseous fuel product by catalytic conversion of light petroleum products.

II. ENERGY RESOURCE/PRODUCTION IN KOREA

A. OVERVIEW

Globally, reserves of coal account for approximately 90 percent of the estimated fossil fuel reserves. The remainder is divided nearly equally between petroleum and natural gas with a small, but not negligible, reserve in the form of tar-sand oils and shale oils.

The average heat equivalent of one metric ton of coal is 28 million BTU's. The total energy content of the estimated coal reserves, 7.6×10^{12} metric tons, is 7.1×10^{15} Watt-years.

If coal is used at the present consumption level, it will last for 3100 years. If coal is supplied at the present growth rate, it will last for 346 years.

The total energy content of the estimated petroleum reserves is 2×10^{12} barrels. If the present petroleum consumption rate does not increase, an extremely unlikely assumption, the petroleum will last for 121 years. But if the present growth consumption rate continues in the future, then oil will last fro 31 years.

The total natural gas estimated is 10^{16} cubic ft. which will last for 39 years at continued current growth rates.

Internationally the interchange of energy resources due to the limitation of petroleum and natural gas must be considered in the near future.

In Korea, the major energy resources such as oil and natural gas have not been discovered, and there is low probability that any exist. There are few energy resources except some hard coal, and even that is difficult to mine because the coal deposits are deep and the quality is ppor (5,600 k cal/kg in 1950, 4,700 k cal/kg at present).

Petroleum accounts for 61 percent of the energy consumption in Korea. Korea and Japan continue to explore the continental shelf to find oil.

Geologically and climatically, water offers limited possibility for development. Atomic energy offers the possibility of extending energy resources in Korea.

B. COAL

Coal reserves have been reported in about ten large fields and several smaller ones. Most of the reserves are located in mountainous regions of the northeast. In most fields, the reserves are found in a single, steeply pitched seam. The reserves occur in the portions of the seam where the thickness exceeds 0.5 meters.

All Korean coal reserves are low-grade anthracite with a high ash content and an average heat value of 18.7 MJ/kg. Total anthracite resources are estimated to be 28.1 trillion MJ. Of these resources, 12.1 percent are proven, 12.3 percent are probable, and the rest are possible. Possible sources are divided into two categories: the first (10.7 trillion MJ) contains minable quantities of anthracite; and

the second (10.5 trillion MJ), contains no anthracite that could be mined using current technologies.

The geologic conditions of the coal fields in Korea make mining difficult. All anthracite is mined by labor-intensive underground techniques.

The steep pitches and geologic faults and folds of Korean coal mines result in low productivity and limit vertical excavation to 25-27 meters per year. This depth, in turn, determines the maximum annual output.

Anthracite production increased steadily between 1970 and 1979 except for 1972 and 1976, when production fell below the level for the previous year. Despite the overall growth, anthracite production is a relatively stagnant industry. Although it increased by almost 42 percent between 1970 and 1975, it grew by only 3.5 percent between 1975 and 1979.

There are 237 companies mining anthracite in Korea. Dai Han Coal Company's (DHCC) share declined from 36 percent in 1970 to 26 percent in 1979. Six large consolidated private mines produced 24 percent in 1979, up from 14 percent in 1970. Small private firms account for the balance of the output.

DHCC owns seven coal mines of various sizes. In 1979, the seven mines porduced 87.9 billion MJ. Overall Korean production in 1979 reached 340.5 billion MJ (Figure 5).

The difficult mining conditions also contribute to safety problems in the mines. In 1978, 4,802 mine accidents were recorded, more than half of which were caused by roof collapses

Year	Producer DHCC	Large Private Firms	Small Private Firms	TOTAL
1970	83.3	31.9	116.6	231.8
1971	80.5	34.6	124.0	238.1
1972	71.2	34.7	126.0	231.9
1973	79.6	42.2	132.0	253.8
1974	82.5	54.3	148.6	285.4
1975	85.5	65.9	177.6	329.0
1976	86.3	63.1	157.8	307.2
1977	84.3	72.8	165.8	322.9
1978	87.4	75.5	174.7	337.6
1979	87.9	72.4	180.2	340.5

Source: "Fossil Energy Evaluation: Republic of Korea," Hagler, Bailly & Company, September 30, 1980, p. 2.17. [Ref. 2]

Figure 5. Anthracite Production in ROK, 1970-1979 (billion MJ)

and transportation incidents. Because of safety problems, miners' wages are 23 percent above those of the average worker.

Production costs vary depending on the size and depth of the mine. In general, unit capital and operating costs increase as the mine becomes smaller or deeper or both. The costs can range from $1.00/thousand MJ for large shallow mines to $3.72/thousand MJ for small deep mines.

C. PETROLEUM

Korea has no known economically exploitable domestic oil reserves. In 1975, petroleum was reportedly discovered in the P'ohang area at a depth of 1,500 meters, but the discovery was apparently not large enough for commercial development. Furthermore, according to the Resource Assessment report, onshore deposits of hydrocarbons are highly unlikely.

The last hope for Korean domestic oil production lies offshore. Even here, though, if oil and gas are present, there is only a 5 percent chance that oil-in-place could be as high as 1.4 billion barrels (bb), and a 5 percent chance that gas-in-place could be as high as 0.44 trillion cubic feet (TCF) [Figure 6).

The exploration efforts continue despite the failure of earlier efforts to yield commercial deposits. For adminstrative purposes, Korea had divided its offshore area into nine lease blocks. Foreign concessionaires have relinquished exploration rights in all but block 5. This withdrawal was apparently prompted by discouraging exploration results.

RESOURCES IN PLACE

Oil		Gas	
Probability*	Resources (bb)	Probability	Resources (tcf)
0.05	1.40	0.05	0.44
0.50	0.70	0.50	0.25
0.95	0.03	0.95	0.07

ESTIMATED RESERVES**

Oil		Gas	
Probability	Amount (bb)	Probability	Amount (bb)
0.01	0.4900	0.01	0.3300
0.10	0.2450	0.10	0.1875
0.19	0.0105	0.19	0.0525
0.80	0	0.80	0

*Probabilties show the odds that resources are at the level indicated or higher.

**Reserves were calculated using U.S. Outer Continental Shelf exploration success rates (20%) and average recovery factors (35% for oil, 75% for gas).

Source: "Fossil Energy Evaluation: Republic of Korea," Hagler, Bailly & Company, September 30, 1980, p. 245. [Ref. 2]

Figure 6

In addition, under pressure from the United States, Korean companies gave up exploration rights to several blocks that were claimed by the People's Republic of China. Presumably, before these blocks can be further explored, the countries involved must negotiate a political settlement. Thus, only Blocks 5 and 7 offer immediate possibilities for exploration. In 1978, Korea and Japan ratified a Continental Shelf Development Agreement under which they will jointly own and explore these blocks.

A test well was drilled in Block 5 in May 1980. Since then, several other test wells were drilled, but they failed to yield commercial deposits. However, Korea continues the exploration efforts.

According to the preliminary Resource Assessment report, the resources-in-place in Blocks 5 and 7 could be significant: there is a 5 percent probability of up to 1.4 billion barrles of oil and 0.44 trillion cubic feet of gas.

These estimates are conditioned by the assumption that oil and gas are present. Thus far, most of the prospects tested were dry holes. The Resource Assessment report did not contain estimates of the dry hole probabilities. Careful analysis of all geological and geographical data is necessary to produce these probabilities.

D. GAS

Korea has no proven natural gas reserves whatsoever. There may be some prospects for natural gas offshore. Although

drilling results to date have been disappointing, the government plans to continue offshore explorations. However, Korea uses propane, butane, and naphtha from its refineries to produce city gas. Naptha feedstock is used to convert light petroleum products into a methane-like produce and then butane is used to boost its caloric value. Korea also uses LPG/air injection plants as standby units and for peak-sharing.

All the gas produced is used for cooking in large multi-family dwelling units.

Because home cooking and heating systems are much less expensive and more widely used than manufactured gas systems, they are not likely to replace the conventional systems in residences. Instead, gas is used primarily in new, large, multifamily dwellings, where home heating tends to be provided by central heating systems.

Korea is considering investing in foreign countries, such as Indonesia in order to meet increasing gas needs with products other than LPG, and to diversify the energy resources.

E. NUCLEAR ENERGY

Nuclear power is a significant potential energy source which could reduce oil usage. Its development has been slowed by the potential environmental pollution, anti-nuclear feelings, and accidents of plants at Three Mile Isalnd in the U.S.A. and others in Japan. However, the countries with few energy reserves encourage the building of nuclear power plants. Korea, Japan, and France are examples, In 1979, Korean nuclear

power capacity was 0.595 million KW with one plant; four plants with 3.2 million KW were under construction, and two plants with 1.8 million KW were planned. With this nuclear power capacity, Korea ranked 18th in the world in 1979.

Nuclear power isn't an energy source to interchange with oil directly like natural gas, coal, and solar energy. However Korea considers it as a significant interchangible energy source.

The total estimated uranium reserve is 4900 tons; however its quality is very low.

F. THE OTHERS

Solar energy may be considered a useful energy source by the 21st century. However its current usage is low because of high costs. Korea is planning to construct 105×10^3 solar houses by 1986 and 545×10^3 houses by 1991.

The total estimated water power capability is 3,012 MW and the annual production of water power is 712 MW. Water offers limited possibility for development under geological conditions in Korea. However Korea plans to increase water power from 0.712 million KW at present to 1.81 million KW in 1991 because it has no pollution and construction is conventional.

Korea assumes that tidal power will be a significant energy source much later. The West coast of Korea has about 9 meters of tidal difference, and there are plans to construct a pilot plant in 1988 which will produce 0.4 million KW.

III. ENERGY RESOURCE IMPORT IN KOREA

A. OVERVIEW

Since energy sources are limited in Korea, they must be imported from other countries. Prior to the 1960's when Korea was considered an undeveloped country with low energy requirements, it was not necessary to import substantial energy supplies. In 1961, energy sources were imported to furnish 8.5 percent of her annual energy consumption: petroleum 8 percent and coal 0.5 percent. In the 1970's, Korea began to increase imports. For example, in 1970, Korea imported 9.2 MTOE or 46.8 percent of the annual energy consumption. In 1978 it reached 24.2 MTOE or 66.7 percent of the annual energy consumption with petroleum taking 61.0 percent, coal 4.1 percent, and atomic power 1.6 percent.

The Korean government recognizes that the importation of energy resources must increase in order to maintain a continuous economic growth.

Korea has two major problems associated with the import of petroleum.

1. The price of petroleum is increasing more rapidly than other energy sources.
2. There is no guarantee of their ability to import a sufficient amount of petroleum to support an economic growth in Korea at any price.

These two factors conspire to limit the economic gorwth of Korea.

B. COAL

Traditionally, Korea has imported only bituminous coal. Recently, however, domestic production has been inadequate to meet the demand for anthracite, and Korea has begun importing anthracite as well. Dai Han Coal Company accounted for 94 percent of these imports in 1979. In 1978, only 0.646 million tons (16.96 billion MJ) of anthracite were imported. By 1979, these imports had risen to 2.017 million tons (50.63 billion MJ). One reason for the rapid increase in import demand is the desire to add 0.7 million tons to the current total stockpile of 1.3 million tons.

Major countries for supplying anthracite coal to Korea include the United States, Peru, South Africa, Swaziland, and Vietnam. In 1978, CIF prices of anthracite ranged from $42.5/ton to $57.1/ton, with vietnamese imports the most expensive (Figure 7). Anthracite imports are received at south-east ports such as Pusan, Ulsan, Mukho, and Masan and stored at the north-west port, Incheon, the major storage and distribution center for anthracite.

Bituminous coal imports are used for steel production at Pohang and for coal fired thermal power plants. Until 1972, the bituminous coal imports were less than 0.5 percent of annual energy consumption. After 1973, the imports increased rapidly because of the impact of the oil crisis. Bituminous coal imports were 2.3 million tons (63.56 billion MJ) in 1978 and 3.8 million tons (105.74 billion MJ) in 1979.

IMPORT PRICES CIF FOR ANTHRACITE
(1978 U.S. $)

Country of Origin	Heat Content (kcal/kg)	($/ton)	($/thousand MJ)
U.S.A.	6,500	57.1	2.10
Vietnam	6,000	55.9	2.23
Australia	5,500	42.5	1.85
South Africa	6,000	45.1	1.80

IMPORT PRICES FOB FOR BITUMINOUS COAL
(1978 U.S. $)

Country of Origin	($/ton)
Australia (Pacific Ocean area)	26.00
South Africa	20.00

Source: "Fossil Energy Evaluation: Republic of Korea," Hagler, Bailly & Company, September 30, 1980, p. 210. [Ref. 2]

Figure 7. Import Prices for Anthracite

The major suppliers include the United States, Canada, Australia, Indonesia, and the Philippines. Most of the bituminous coal is metallurgical rather than steam coal.

Most bituminous coal is unloaded at Pohang, which has large, modern coal-handling facilities. However, Pohang cannot be used for unloading anthracite because there is no railroad link between Pohang and Incheon.

To guarantee the security of supplies, Korean firms have initiated several joint coal mining ventures with other countries with the agreement that some or all the coal output is exported to Korea. Specifically, Korean firms have entered into, or propose undertaking, one bituminous and four anthracite coal mining ventures in Australia, two bituminous coal ventures in Canada, and one bituminous coal mining joint venture in Indonesia (Figure 8). The Korean share of equity ranges from 5 percent to 100 percent, and annual coal imports per project are scheduled to vary between 1 and 2 million tons of anthracite and 0.5 and 3 million tons of bituminous coal depending on the project.

C. PETROLEUM

Korea imports large quantities of crude oil. To balance refining capacity, it also imports and exports relatively small quantities of oil products.

Imports of crude oil to Korea have increased from 9.18 million tons in 1970 to 22.14 million tons in 1978. All

FOREIGN COAL VECTURES OF ROK FIRMS

Coal Type	Country/ Coalfield	ROK Company	Foreign Partner	Korean Equity (%)	Start Date	Annual Imports (thousand tons)
Anthracite	United States					
	Martarano, Philadelphia	Dae Woo	Angelo Martarano	50	1980	600
	Australia					
	Baralaba, Queensland	Dae Woo	Crusader Oil	49	1989	1,000
	United States					
	F.A. Potts, Pennsylvania	San Sung	GMP Land	33	1980	500
	Australia					
	Yarrabee Queensland	Hyundai Dae Sung	CSR	5	1980	1,000
	United States					
	Donaldson, Pennsylvania	Korea Tacoma	Donaldson Coal Co.	60	1980	300
	Sharp Mt. Region, Pennsylvania	Hyosung	Pilgrim Co.	100	1980	200

Figure 8

Figure 8 - Continued

FOREIGN COAL VENTURES OF ROK FIRMS

Coal Type	Country/ Coalfield	ROK Company	Foreign Partner	Korean Equity (%)	Start Date	Annual Imports (thousand tons)
Bituminous	United States					
	Tanoma, Pennsylvania	P'ohang Manufac. Co.	B&T Co.	100	1979	646
	Australia					
	Mt. Thorley New South	P'ohang Manufac. Co.	R.W. Miller	20	1979	1,000
	Canada					
	Sukunka, British Columbia	P'ohang Manufac. Co.	British Petroleum Coal Ltd.	-	1981	1,000
	Australia					
	Drayton, New South Wales	Hyundai Dai Sung	Shell Thiess	5	1980	500
	Newland, Queensland	Dae Woo	MIM	10	1980	1,000

Figure 8 - Continued

FOREIGN COAL VENTURES OF ROK FIRMS

Coal Type	Country/ Coalfield	ROK Company	Foreign Partner	Korean Equity (%)	Start Date	Annual Imports (thousand tons)
Bituminous	Canada					
	Quintette, British Columbia	Sam Sung	Denison	10-20	1980	500
	Australia					
	Clermont, Queensland	Hyundai	White Industry	35	1983	1,000
	Indonesia					
	Mahakam Kalimantan	Kukje	PA Tanito-harum	70	1980	1,000

Source: "Fossil Energy Evaluation: Republic of Korea," Hagler, Bailly & Company, September 30, 1980, p. 2.12. [Ref. 2]

imports came from the Persian Gulf. In 1970, Kuwait, Saudi Arabia, and Iran provided approximately equal amounts of crude oil. Saudi Arabia supplys over half of Korea's crude oil, Kuwait, 32 percent, and Iran, 11 percent. Other producers provide the remaining 3.7 percent (Figure 9). In 1978, Korea received 2.2 percent of all Middle East crude oil exported.

Like most countries, Korea has been unable to avoid the sharp increases in the crude oil import price. Korea's import cost rose from an average of about $2.83/bbl ($0.45/thousand MJ) in 1973 to an average of $12.93/bbl ($2.07/thousand MJ) by the beginning of 1979. Currently, average crude oil costs have reached approximately $34/bbl ($5.44/thousand MJ) (Figure 10).

In 1979, the refined oil imports of Korea were 10 million barrels--the largest ever reached. However, product imports represent only 5.1 percent of all petroleum imports.

Korea also exports petroleum products, with light petroleum products the major part of the export volume. In 1979, Naphtha accounted for two-thirds of the total of 659,000 barrels exported.

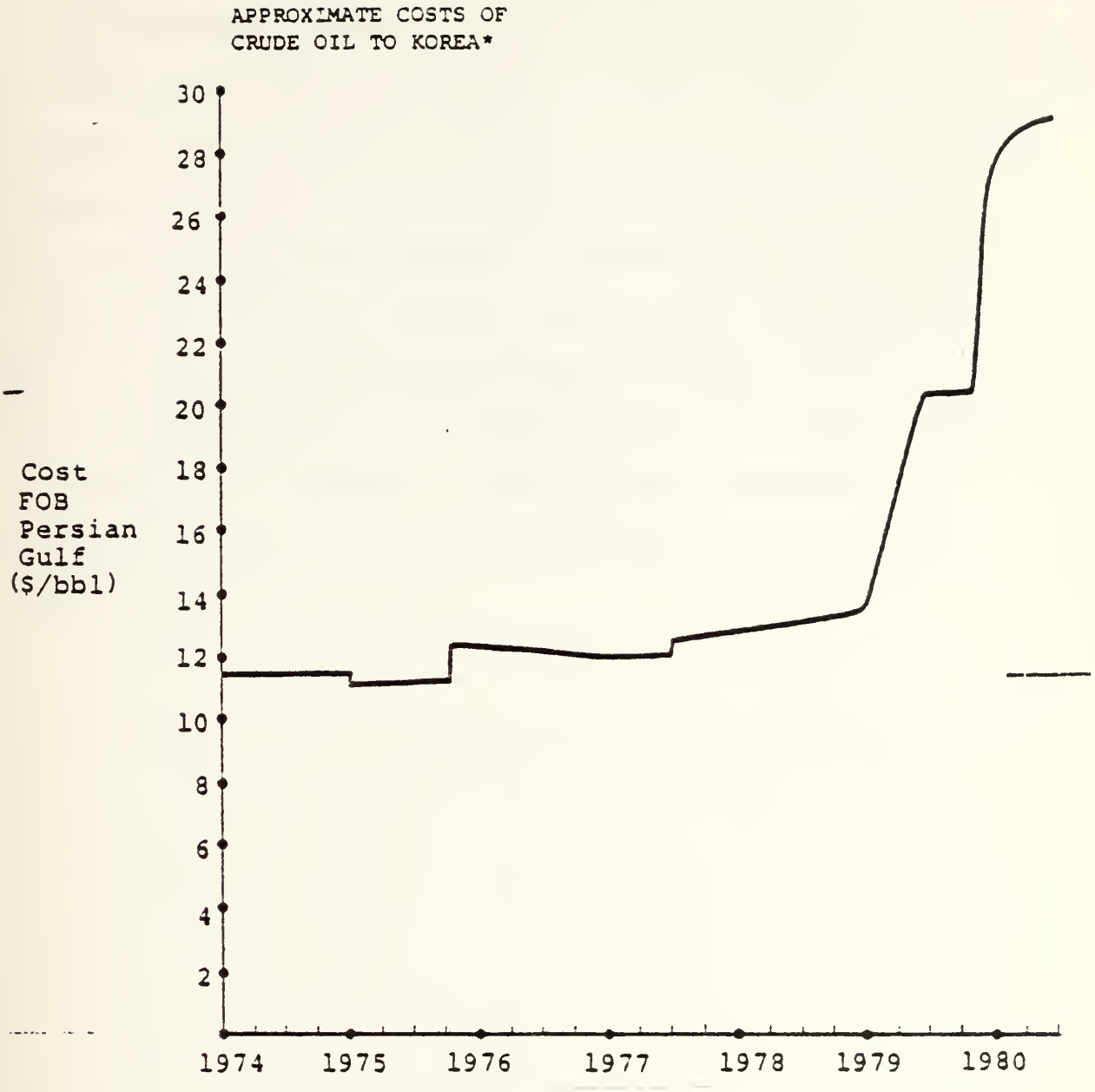
Consistently importing heavy products and exporting light products indicates that Korea may be buying lighter crude oil than required. If Korea imports heavier crudes than present, and the heavier crude produces proportionately heavier products, it might reduce crude purchasing and transportation costs.

SOURCES OF KOREAN CRUDE OIL
(million barrels)

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Kuwait	24.5	25.0	48.0	46.6	19.4	18.9	53.6	52.4	49.7	50.8	-
Saudi Arabia	12.5	22.0	30.5	36.9	63.4	73.7	51.9	52.6	83.4	85.8	-
Iran	18.9	22.2	10.9	2.8	4.6	3.3	0.9	14.2	16.8	12.9	-
Neutral Zone	-	-	-	5.5	15.8	16.8	10.2	10.9	0.9	3.9	-
Other	-	-	-	0.7	-	-	1.2	2.2	3.8	3.1	-
TOTAL	55.9	69.2	85.4	92.6	103.2	112.7	117.8	132.4	154.5	166.5	-

Source: "Fossil Energy Evaluation, Republic of Korea," Hagler, Bailly & Company, September 30, 1980, p. 2.48. [Ref. 2]

Figure 9



Source: "Fossil Energy Evaluation, Republic of Korea," Hagler, Bailly, & Company, September 30, 1980, p. 2.50. [Ref. 2]

Figure 10. Approximate Costs of Crude Oil to Korea

D. THE OTHERS

Korea does not currently import natural gas. However, it is discussing importing LNG with potential suppliers and is seeking to buy 3 million tons (156 billion MJ) of LNG from Indonesia in 1984. Pipeline imports are unlikely unless reunification with North Korea is achieved.

Korea did not import nuclear power plants and equipment prior to 1976. Korean nuclear power production began in 1976 and accounted for 0.018 MTOE in 1977, 0.58 MTOE in 1978, 0.782 MTOE or 1.8 percent of annual energy consumption in 1979. Korea plans to expand nuclear power to 20.71 MTOE in 1991.

IV. LONG-TERM ENERGY REQUIREMENTS IN KOREA

A. OVERVIEW

The long-term energy requirements for Korea were predicted by four different regression models using several variables including GNP, population, and the previous year energy requirements. The data for the years 1961 to 1978 were used for the forecast. The forecasts came from models based on total energy, sector type, source type, and by sector and source type.

Korea has a plan to substitute other energy sources for oil. The long-term energy requirements by sources were computed by adding and subtracting an energy substitution plan to the long-term energy estimations computed with source type data. For instance, the long-term oil requirement was computed by subtracting the oil substitution plan quantity from the oil forecast. The other energy requirements were computed by adding the oil substitution plan amount to the other values which were computed by the model.

B. HISTORICAL DATA

The Korean energy consumption is highly related to GNP, population, and previous year's energy consumption. This conclusion was the result of analyzing historical data. The energy consumption elasticity to GNP is defined as:

$$\alpha = \frac{(\Delta E/E)}{(\Delta Y/Y)},$$

where E is annual energy consumption and Y is Gross National Product. Average elasticity (α) was 0.897 from historical data. The per capita energy consumption elasticity to per capita GNP is defined as:

$$\alpha_n = \frac{(\Delta E_n / E_n)}{(\Delta Y_n / Y_n)}$$

where E_n is per capita energy consumption and Y_n is per capita Gross National Product. Average elasticity (α_n) was 0.863 from the past data. The energy consumption patterns were established over many years. Therefore, we can ssume that current energy consumption relates to previous energy consumption. The energy consumption elasticity to previous energy consumption is defined as:

$$\alpha_t = \frac{(\Delta E_t / E_t)}{(\Delta E_{t-1} / E_{t-1})},$$

where E_t is energy consumption in this year and E_{t-1} is energy consumption one year ago. Average elasticity (α_t) was 0.524 from the past data.

The previous results indicate the GNP, population, and previous year's energy consumption can be used as variables in a multivariable regression model to estimate the long-term energy requirements. First, we should estimate GNP and population in order to forecast the long-term energy requirements.

The recent Gross National Product growth rates are assumed as follows:

1979-1980: 9%

1981-1991: 10%

1992-2001: 9%

The actual values of GNP, population, total energy consumption are shown (Figure 11). The estimated values of GNP, population and the per capita GNP are shown in Figure 12. Figure 13 lists the annual energy consumption by sector, and the annual energy consumption by source is shown in Figure 14.

C. MODELS FOR PREDICTION

Four models were used to predict the long-term energy requirements. The variables for the models are GNP, population, previous year's energy consumption, and a dummy variable which was added to evaluate the effect of the oil crisis. If the dummy variable (D) is one, then the oil crisis is not considered to affect long-term energy requirements; if the dummy variable is zero, the oil crisis is assumed to affect those requirements. The equations of the four models are given in Figure 15. In Model I, the log-transformed annual energy requirement is a function of the log-transformed GNP and the dummy variable D.

In Model II, the log-transformed annual per capita energy requirement is a function of the log-transformed per capita GNP, and the dummy variable D. In Model III, the log-transformed annual energy requirement is a function of the

Year	Annual Energy Consumption (unit: TTOE***)	% *	GNP (Bil ₩**)	% *	Population (1000 people)	% *
1961	9,862	-	3,004.58		25,766	
1962	10,474	6.2	3,071.14	2.2	26,513	2.86
1963	11,064	5.6	3,350.65	9.1	27,263	2.82
1964	11,596	4.8	3,671.50	9.6	27,984	2.65
1965	12,127	4.6	3,884.99	5.8	28,705	2.58
1966	13,100	6.0	4,378.48	12.7	29,436	2.55
1967	13,895	6.1	4,669.39	6.6	30,131	2.36
1968	15,554	11.9	5,195.61	11.3	30,838	2.34
1969	17,402	11.9	5,911.39	13.7	31,514	2.29
1970	19,737	13.4	6,347.70	7.4	32,241	2.21
1971	21,273	7.8	6,908.74	8.8	32,883	1.99
1972	22,054	3.7	7,305.01	5.7	33,505	1.89
1973	25,273	14.6	8,377.08	14.7	34,103	1.78
1974	25,510	0.9	9,009.39	7.5	34,692	1.73
1975	27,076	6.1	9,644.24	7.0	35,281	1.69
1976	29,805	10.1	11,016.39	14.2	35,860	1.64
1977	33,074	10.9	12,.75.23	10.5	36,463	1.68
1978	36,157	9.3	13,693.26	12.5	37,019	1.52

*percent is annual change

**W: won (Korean currency

***TTOE: Thousand tons of oil equivalent

Source: "Comprehensive Plan," p. 153. [Ref. 3]

Figure 11. Data of Annual Energy Consumption, GNP, and Population

Year	GNP (Bil W**)	%*	NNP (100 W)	%*	Population (1000 people)	%*
1979	14,925.65	9.0	397	7.3	37,605	
1980	16,268.96	9.0	426	7.3	38,197	1.6
1981	17,895.58	10.0	461	8.2	38,807	1.6
1982	19,685.14	10.0	499	8.2	39,437	1.6
1983	21,653.65	10.0	540	8.2	40,084	1.64
1984	23,819.02	10.0	585	8.3	40,747	1.65
1985	26,200.92	10.0	633	8.2	41,418	1.65
1986	28,821.01	10.0	685	8.2	42,088	1.62
1987	31,703.01	10.0	742	8.3	42,752	1.58
1988	34,773.42	10.0	801	8.0	43,401	1.52
1989	38,360.77	10.0	871	8.7	44,032	1.45
1990	42,196.84	10.0	945	8.5	44,642	1.39
1991	46.416.53	10.0	1,026	8.6	45,251	1.36
1992	50,594.02	9.0	1,103	7.5	45,859	1.34
1993	55,147.48	9.0	1,187	7.6	46,467	1.33
1994	60,110.75	9.0	1,277	7.6	47,074	1.31
1995	65,520.72	9.0	1,374	7.6	47,631	1.18
1996	71,417.58	9.0	1,479	7.6	48,282	1.37
1997	77,845.17	9.0	1,592	7.6	48,885	1.24
1998	84,851.23	9.0	1,715	7.7	49,474	1.20
1999	92,487.84	9.0	1,848	7.7	50,053	1.17
2000	100,811.74	9.0	1,992	7.8	50,619	1.13
2001	109,884.80	9.0	2,146	7.7	51,176	1.10

*Percent is annual change

**GNP: 1975 constant dollar

Source: "Comprehensive Plan," p. 158. [Ref. 3]

Figure 12. Estimated GNP, NNP, and Population

Year	Industry	% *	Home and Commerce	% *	Trans-portation	% *	Other	% *	Total	% *
1961	4.276		4.057		.597		.785		9.715	
1962	3.510	(-18.0)	5.290	(30.4)	.584	(-2.2)	.941	(19.9)	10.325	(6.3)
1963	2.510	(-28.5)	6.799	(28.5)	.528	(-9.6)	1.044	(10.9)	10.881	(5.4)
1964	2.848	(13.5)	7.028	(3.4)	.468	(-11.4)	1.039	(-0.5)	11.383	(4.6)
1965	3.139	(10.2)	7.087	(0.8)	.673	(43.8)	1.019	(-1.9)	11.918	(4.7)
1966	3.545	(12.9)	7.260	(2.4)	.958	(42.3)	1.103	(8.2)	12.866	(7.9)
1967	3.972	(12.1)	7.359	(1.4)	1.302	(35.9)	.907	(-17.8)	13.540	(5.2)
1968	4.595	(15.6)	7.956	(8.1)	1.734	(33.3)	.844	(-6.9)	15.129	(11.7)
1969	5.318	(15.7)	8.489	(6.7)	2.025	(16.8)	1.244	(47.4)	17.076	(12.9)
1970	5.805	(9.2)	9.450	(11.3)	2.301	(13.6)	1.963	(57.8)	19.519	(14.3)
1971	6.397	(10.2)	9.643	(2.0)	2.681	(16.5)	2.428	(23.7)	21.149	(8.4)
1972	6.667	(4.2)	9.801	(1.6)	2.820	(5.2)	2.695	(11.0)	21.983	(3.9)
1973	8.361	(25.4)	10.403	(6.1)	3.519	(24.8)	2.893	(7.3)	25.176	(14.5)
1974	9.046	(8.2)	10.197	(-2.0)	3.329	(5.4)	2.828	(-2.3)	25.400	(0.9)
1975	10.412	(15.1)	10.340	(1.4)	3.209	(-3.6)	3.009	(6.4)	26.970	(6.2)
1976	11.538	(10.8)	11.129	(7.6)	4.007	(24.8)	3.009	(0.0)	29.683	(10.1)
1977	12.954	(12.3)	11.962	(7.5)	4.792	(19.6)	3.337	(10.9)	33.045	(11.3)

*Percent is annual change Unit: MTOE

Source: "Comprehensive Plan," p. 164 . [Ref. 3]

Figure 13. Annual Energy Consumption by Sector

Year	Hard Coal	%*	Soft Coal	%*	Oil	%*	Water Power	%*	Atomic Power	%*	Char-coal	%*	Total	%*	Electric Power	%*
1961	3,226		47		790		163		-		5,636		9,862		443	
1962	3,846	(19.2)	119	(53.1)	984	(24.6)	176	(7.9)	-		5,349	(-5.1)	10,474	(6.2)	495	(11.2)
1963	4,530	(17.8)	104	(-12.6)	1,100	(1.6)	182	(3.4)	-		5,148	(-3.8)	11,064	(5.6)	559	(12.9)
1964	5,025	(10.9(	110	(5.7)	1,091	(-.01)	188	(3.3)	-		5,182	(0.7)	11,596	(4.8)	675	(20.8)
1965	5,291	(5.3)	77	(-30.0)	1,439	(31.8)	178	(-5.4)	-		5,142	(-0.8)	12,127	(4.6)	812	(20.3)
1966	6,050	(14.3)	59	(-23.4)	2,134	(48.3)	246	(38.2)	-		4,611	(-10.4)	13,100	(8.0)	972	(19.7)
1967	5,627	(-7.0)	58	(-1.7)	3,578	(67.7)	238	(-3.3)	-		4,394	(-4.8)	13,895	(6.1)	1,228	(26.3)
1968	5,461	(-3.0)	44	(-24.2)	5,143	(43.7)	232	(-2.6)	-		4,674	(6,3)	15,554	(11.9)	1,306	(6.4)
1969	5,649	(3.4)	60	(36.4)	6,981	(35.7)	357	(53.8)	-		4,355	(-6.9)	17,402	(11.9)	1,925	(47.4)
1970	5,943	(5.2)	52	(-13.4)	9,186	(31.6)	305	(-14.6)	-		4,251	(-2.4)	19,737	(13.4)	2,292	(19.1)
1971	5,955	(0.2)	37	(-29.9)	10,844	(18.0)	330	(8.2)	-		4,107	(-3.4)	21,273	(7.8)	2,635	(14.9)
1972	6,084	(2.2)	22	(-40.6)	11,616	(7.1)	342	(3.6)	-		3,990	(-2.9)	22,054	(3.7)	2,960	(12.3)
1973	7,244	(19.1)	427	(1841.)	13,624	(17.3)	306	(-10.6)	-		3,672	(-8.0)	25,273	(14.6)	3,706	(25.2)
1974	7,222	(-0.3)	552	(29.3)	13,735	(0.8)	476	(55.6)	-		3,525	(-4.1)	25,510	(0.9)	4,209	(13.6)
1975	7,556	(4.6)	518	(-6.2)	15,161	(10.4)	421	(-11.6)	-		3,420	(-3.0)	27,076	(6.1)	4,959	(17.8)
1976	7,820	(3.5)	1,046	(101.9)	17,317	(14.2)	447	(6.2)	-		3,175	(-7.2)	29,805	(10.1)	5,779	(16.5)
1977	8,252	(5.5)	1,385	(32.4)	19,954	(15.2)	348	(-22.2)	18		3,117	(-1.9)	33,074	(10.9)	6,647	(15.0)
1978	8,448	(2.4)	1,495	(7.9)	22,143	(10.9)	452	(29.9)	581	(2227.7)	3,038	(-2.5)	36,157	(9.3)	7,877	(18.5)

Source: "Comprehensive Plan," p. 174 [Ref. 3]

*Percent is annual change

Unit: Oil 10^3 Ton

Figure 14. Annual Energy Consumption by Source

Case	Equation of Model
Model I	$\ln E = \alpha_1 + \alpha_2 \ln Y + \alpha_3 D$
Model II	$\ln(E/N) = \alpha_1 + \alpha_2 \ln(Y/N) + \alpha_3 D$
Model III	$\ln E = \alpha_1 + \alpha_2 \ln Y + \alpha_3 \ln E_{t-1} + \alpha_4 D$
Model IV	$\ln(E/Y) = \alpha_1 + \alpha_2 \ln Y + \alpha_3 (Y/N) + \alpha_4 D$

where:

E: annual energy consumption

Y: Gross National Product

N: total population

E_{t-1}: Previous year's energy consumption

D: dummy variable

(if D = 1: oil crisis effects not considered

if D = 0: oil crisis effects considered)

Figure 15. Models

the log-transformed GNP, the previous year's energy consumption, and the dummy variable D. In Model IV, the log-transformed annual energy consumption per GNP is a function of the log transformed GNP, the per capita GNP, and the dummy variable D.

After model runs using the total energy data, sector data, source data, and sector and source data, it was concluded that Model III was superior for all data types. Only the results for all the models using the total energy data are shown in Figure 16.

Case	Equation	Coefficient
Model I	$\ln E = 1.93358 + 0.897007 \ln Y + 0.066643D$	$R^2 = 0.9954$, D.W. = 0.7623
Model II	$\ln(E/N) = 0.812957 + 0.862683 \ln(Y/N) + 0.0630143D$	$R^2 = 0.9913$, D.W. = 0.7181
Model III	$\ln E = 0.625102 + 0.462763 \ln Y + 0.523726 \ln E_{t-1} + 0.0650035D$	$R^2 = 0.998$; D.W. = 1.8405
Model IV	$\ln(E/Y) = 3.09411 - 0.208619 \ln Y + 0.1418051(Y/N) + 0.0709946D$	$R^2 = 0.8833$, D.W. = 0.8112

Y: GNP (billion W) D: Dummy variable
N: Population (thousand people)

Figure 16. The Results of the Model Runs using the Total Energy Data

The criteria were coefficients of determination (R^2) and Durbin-Watson statistics. Model III has coefficients of determination and Durbin-Watson statistics that are larger than other models. Therefore, Model III was used to forecast for all data cases. The results of Model III using sector data and source data are shown in Figure 17.

D. RESULTS OF PROJECTIONS

1. The Results of Projections Based on Total Energy Requirements Data

Historical total energy consumed data energy and Model III were used to predict the total amount of annual long term energy requirements. The results are: 48.9 MTOE in 1981, 129.2 in 1991 and 305.2 in 2001 (Figure 18). During the twenty years from 1981 to 2001, the forecast shows that the annual energy requirement in 2001 increased to more than six times the annual energy requirement in 1981.

2. The Results of Projections Computed Using Sector Data

The annual energy consumption data of each sector for the period 1961-77 and Model III were used to predict the long term annual energy requirements of each sector. The results were: the Industrial sector will require 21.632 MTOE in 1981, 72.627 in 1991 and 217.075 in 2001; the transportation sector will require 8.519 MTOE in 1981, 37,686 in 1991 and 145.394 in 2001; the Home and Commercial sector will need 14.753 MTOE in 1981, 25,303 in 1991, and 41.346 in 2001. The miscellaneous energy needs will require 12.086 MTOE in 2001.

	Case	Resulting Equation	Coefficients
Sectors	Industry	$\ln E = -2.40186 + 1.24142 \ln Y + 0.02307 \ln E_{t-1}$	$R^2 = 0.9978$ D.W. = 2.1465
	Transportation	$\ln E = -4.56538 + 1.15217 \ln Y + 0.26202 \ln E_{t-1} + 0.22407 D$	$R^2 = 0.9861$ D.W. = 3.1582
	Home and Commerce	$\ln E = 2.67272 + 0.37152 \ln Y + 0.34447 \ln E_{t-1} + 0.06452$	$R^2 = 0.9854$ D.W. = 1.5302
	The Others	$\ln E = 1.88692 + 0.42479 \ln Y + 0.27622 \ln E_{t-1} + 0.06720D$	$R^2 = 0.9402$ D.W. = 3.3156
	Oil	$\ln E = -1.22176 + 0.94880 \ln Y + 0.22327 \ln E_{t-1} + 0.07467D$	$R^2 = 0.9974$ D.W. = 2.8521
Sources	Coal	$\ln E = 2.88435 + 0.18021 \ln Y + 0.49310 \ln E_{t-1} - 0.02091D$	$R^2 = 0.952$ D.W. = 2.0517
	Charcoal	$\ln E = 11.91780 - 0.36912 \ln Y - 0.04890 \ln E_{t-1} + 0.06146D$	$R^2 = 0.9813$ D.W. = 2.0172
	Hydroric Electricity	$\ln E = -0.20621 + 0.69675 \ln Y - 0.03696 \ln E_{t-1} - 0.0124D$	$R^2 = 0.8476$ D.W. = 1.9695

where: E: annual energy consumption, E_{t-1}: previous year energy consumption,
Y: Gross National Product, D: Dummy Variable (if D = 1: oil crisis not considered; if D = 0, oil crisis considered)
N: Total Population

Figure 17. Result of Model III

Year	Amount (Unit: MTOE)
1981	48.9
1986	79.7
1991	129.2
1996	199.3
2001	305.2

Source: "Comprehensive Plan," p. 160. [Ref. 3]

Figure 18. The Total Energy Requirement Predicted by Total Energy Consumption Data

The energy acquisition rate of the industrial sector increases until 1991, and then it is stable at about 51.5 percent after 1991. The utilization rate of the home and commercial sector decreases continuously from 30 percent in 1981 to 10 percent in 2001. The utilization rate of the transportation sector increases rapidly and continuously from 17 percent in 1981 to 35 percent in 2001 (Figure 19).

3. The Results of Projections Computed by Source Data

The four major energy resources utilized in Korea are oil, coal, charcoal, and water power. Historical data and Model III were used to predict the annual long-term energy requirements for each source.

The results are: oil needs are 31.4 million tons in 1981, 100.6 in 1991, and 289.2 in 2001; coal needs are 9.3 MTOE in 1981, 13.0 in 1981, and 17.7 in 2001. The other sources and more data are shown in Figure 20.

The oil utilization rate will increase from 71.4 percent in 1981 to 93.2 percent in 2001. The coal utilization rate will decrease from 21.2 percent in 1981 to 5.7 percent in 2001. The rates of charcoal and water power will also decrease. These results show that the high oil dependency will create problems unless some oil is replaced by other energy sources. Alternatives offered by the development of interchangeable energy sources, such as coal, nuclear power, water power, and others are necessary.

Year Sector	1981	1986	1991	1996	2001
Industry	21,632	39,637	72,627	125,606	217,075
Transport.	8,519	17,909	37,686	74,228	145,394
Home and Commerce	14,753	19,315	25,303	32,392	41,346
The Others	4,159	5,499	7,274	9,387	12,086
TOTAL	49,063	82,360	142,890	241,613	415,901

Source: "Comprehensive Plan," p. 171. [Ref. 3]

Figure 19. Prediction of Long-Term Energy Requirement by Sector

Unit: MTOE

Year Source	1981	1986	1991	1996	2001
Oil	31.439 (71.4)	56.235 (79.9)	100.649 (86.2)	170.923 (90.3)	289.228 (93.2)
Coal	9.313 (21.2)	11.025 (15.7)	13.060 (17.2)	15.269 (8.17)	17.798 (5.7)
Charcoal	2.647 (6.0)	2.314 (3.3)	1.957 (1.7)	1.682 (0.9)	1.446 (0.5)
Water Power	0.631 (1.4)	0.815 (1.2)	1.123 (1.0)	1.499 (0.8)	2.002 (0.6)
TOTAL	44.030	70.389	116.789	189.373	310.474

Source: "Comprehensive Plan," p. 177. [Ref. 3]

Figure 20. Prediction of Long-Term Energy Requirements by Source

4. The Results of Projections Computed Using Sectors and Sources Data

Four energy consumption sectors--industrial, transportation, home and commercial, and public and other sectors--and four energy sources--oil, coal, electricity, and charcoal--are considered here. Historical data and Model III were used to predict the annual long-term energy requirements for each sector and source. The results and the necessary utilization rate are listed in Figure 21.

E. FINAL RESULTS OF FORECASTS

1. Differences in Projection Results

The estimated annual total energy requirements as forecast by the four alternate data approaches are different (Figure 22). The total energy requirements estimated by sector and source data is larger than the estimations by other data. And the total energy requirements estimated by source data is smaller than the others.

2. Long-Term Energy Requirements by Source

The Korean government has plans to substitute coal, gas, nuclear power, solar energy, wind power, and tidal power for oil. It was assumed that the interchangeable energy source consumption will increase 10 percent per year between 1992 and 2001. The energy substitution plan is shown in Figure 23.

Finally, long-term energy requirements were estimated using the energy substitution plans and prediction results. For oil, long-term energy requirements are computed by

	1981	%	1986	%	1991	%	1996	%	2001	%
1. Industry	22711.1	41.3	45519.8	43.6	93827.8	44.6	184509.4	44.4	369682.0	43.4
Coal	2761.5	12.2	4452.8	9.9	7179.8	7.7	11058.8	6.0	17027.4	4.6
Oil	10730.0	47.2	19132.7	42.0	34115.8	36.3	57552.7	91.2	97047.7	26.3
Elect. Pwr.	9110.7	40.1	21869.7	48.0	52496.9	56.0	115874.0	62.8	255592.0	69.1
Charcoal	108.9	0.5	64.6	0.1	35.3	0.0	23.9	0.0	14.9	10.0
2. Transportation	7237.7	13.2	12976.3	12.4	24955.8	11.9	49761.7	12.0	112335.0	13.2
Coal	85.5	1.2	101.0	0.8	119.4	0.5	138.9	0.3	161.5	0.1
Oil	6752.6	93.3	11366.8	87.6	19133.9	76.7	30640.7	61.6	48047.8	43.7
Elect. Pwr.	398.8	5.5	1507.9	11.6	5702.0	22.8	18981.7	38.1	63125.3	56.2
Charcoal	0.8	0.0	0.6	0.0	0.5	0.0	0.4	0.0	0.4	0.0
3. H. & Comm.	16848.2	30.7	27323.6	26.1	48654.8	23.1	87379.3	21.0	164260.4	19.3
Coal	8756.8	52.0	12457.4	45.6	17721.8	36.4	24373.6	27.9	33513.1	20.4
Oil	2275.1	13.5	5391.9	19.7	12773.6	26.3	27865.8	31.9	60749.7	37.0
Elect. Pwr.	3458.1	20.5	7592.4	27.8	16650.5	34.2	33915.2	38.8	68998.7	42.0
Charcoal	2358.2	14.0	1881.9	6.9	1508.9	3.1	1224.7	1.4	998.9	0.6

Unit: 10^3 tons of equivalent oil

Figure 21. Prediction of Long-Term Energy Requirement by Sector and Source

Figure 21 - Continued

		1981	%	1986	%	1991	%	1996	%	2001	%
4.	Others	8153.1	14.8	18508.6	17.6	43071.3	20.4	93804.8	22.6	206124.2	24.1
	Coal	884.1	10.9	1236.0	6.7	1727.9	4.0	2339.3	2.5	3166.2	1.5
	Oil	6214.9	76.2	15270.4	82.5	37520.1	87.1	84580.2	90.1	190535.4	92.5
	Elect. Pwr.	987.3	12.1	1911.1	10.3	3699.1	8.6	6721.0	7.2	12205.3	5.9
	Charcoal	66.8	0.8	91.1	0.5	124.2	0.3	164.3	0.2	217.4	0.1
5.	Total	54950.1	100.0	104328.3	100.0	210509.7	100.0	415455.2	100.0	852401.7	100.0
	Coal	12487.9	22.7	18247.2	17.5	26748.9	12.7	37910.6	9.1	53868.2	6.3
	Oil	25972.6	47.3	51161.8	49.0	103543.4	49.2	200639.4	48.3	397380.6	46.7
	Elect. Pwr.	13954.9	25.4	23881.1	31.5	78548.5	37.3	175491.9	42.2	399921.3	46.9
	Charcoal	2534.7	4.6	2038.2	2.0	1668.9	0.8	1413.3	0.4	1231.6	0.1

Source: "Comprehensive Plan," p. 179. [Ref. 3]

Unit: MTOE

Year Data type	1981	1986	1991	1996	2001
Total	48.9	79.7	129.2	199.4	305.2
Sector	49.1	82.4	142.9	241.6	415.9
Source	44.0	70.4	116.8	189.4	310.5
Sector & Source	54.9	104.3	210.5	415.5	852.4

Source: "Comprehensive Plan," p. 183. [Ref. 3]

Figure 22. Comparison of Total Energy Requirement by Four Different Data Types

Unit: MTOE

Year Source	1981	1986	1991	1996	2001
Hard coal	2.307	2.689	2.164	2.164	2.164
Bituminous coal	3.687	16.146	33.823	54.473	87.728
Natural gas	-	-	1.445	2.547	4.488
Nuclear power	0.898	5.400	16.691	26.881	43.292
Total power	-	-	0.573	0.923	1.486
Wind power	-	-	-	-	0.911
Solar energy	0.006	0.160	1.145	2.849	7.090
TOTAL	6.898	24.395	55.841	89.837	147.159

Source: "Comprehensive Plan," p. 190. [Ref. 3]

Figure 23. Energy Substitution Plan for Oil

subtracting the total amount of energy in the plan from the forecast for oil. For hard coal, long-term requirements were computed by adding hard coal in the substitution plan to the prediction results of hard coal. For water power, the long-term requirements are equal to the forecast results for water power, because there is no substitution plan for water power. For other sources such as bituminous coal, natural gas, solar energy, tidal power, wind power, the long-term requirements are equal to the amount in the substitution plan because there are no forecast results.

The oil requirement forecast is 81.1 million tons in 1996 and 142.1 in 2001. Using the substitution plan, oil utilization will decrease from 90.3 percent to 42.8 percent in 1996 and from 93.2 percent to 45.8 percent in 2001. On the other hand, imported bituminous coal requirements will increase very rapidly from 3.7 MTOE, or 8.4 percent of the annual energy requirements in 1981 to 87.7 MTOE, or 28.3 percent in 2001. Nuclear power will increase very rapidly from 0.9 MTOE, or 2 percent of the annual energy requirements in 1981 to 43.3 MTOE, or 13.9 percent. The hard coal requirement is 19.9 MTOE, or only 6.4 percent of the total annual energy requirements, and the charcoal requirement is negligible with 0.5 percent in 2001. The final long-term energy requirements by source are shown in Figure 24.

Unit: MTOE

Year Source	1981	1986	1991	1996	2001
Oil	24.541 (55.7)	31.840 (45.2)	44.808 (38.4)	81.086 (42.8)	142.069 (45.8)
Hard Coal	11.620 (26.4)	13.714 (19.5)	15.224 (13.0)	17.433 (9.2)	19.962 (6.4)
Bituminous Coal	3.687 (8.4)	16.146 (22.9)	33.823 (30.0)	54.473 (28.8)	87.728 (29.3)
Gas	0.0	0.0	1.445 (1.2)	2.547 (1.3)	4.488 (1.4)
Charcoal	2.647 (6.0)	2.314 (3.3)	1.957 (1.7)	1.682 (0.9)	1.446 (0.5)
Nuclear Power	0.898 (2.0)	5.400 (7.7)	16.691 (14.3)	26.881 (14.2)	43.292 (13.9)
Water Power	0.631 (1.4)	0.815 (1.2)	1.123 (1.0)	1.499 (0.8)	2.002 (0.6)
Tidal Power	-	-	0.573 (0.5)	0.923 (0.5)	1.486 (0.5)
Wind Power	-	-	-	-	0.911 (0.3)
Solar Energy	0.006 (0)	0.160 (2.3)	1.145 (1.0)	2.849 (1.5)	7.090 (2.3)
TOTAL	44.030	70.389	116.789	189.373	310.474

Percentage in parenthesis is utilization rate

Figure 24. Final Long-Term Energy Requirements

V. CONCLUSIONS AND RECOMMENDATIONS

A. ANALYSIS AND CRITIQUE

1. General

The energy supplies of the Republic of Korea between 1982 and 2001 will be almost entirely controlled by world energy market conditions. Consequently, any supply alternatives need to be developed within the context of world energy markets. This section compares the energy markets with emphasis on the issues of availability, security of supply, production, price projections, and sources of supply.

2. Oil

Oil is currently the dominant fuel in world energy trade. In 1978, the international oil trade was 33.8 million barrels per day (mbd), the international coal trade was almost 1.88 mbd of oil equivalent (mbdoe), and the international gas trade was 2.9 mbdoe. Therefore, the global oil market is almost 12 times as large as the gas market, and 18 times as large as the coal market. Regarding reserves, however, world coal reserves are almost five times as large as those of oil, which are only 1.4 times as large as gas reserves.

The world oil market is less concentrated in reserves, production and exports, than gas and coal market. For example, while the three largest oil exporters account for 48.5 percent of world oil exports, the corresponding figures for coal and gas are 62.9 percent and 65.5 percent respectively.

Oil is the least stable source even though oil is the least concentrated market. The three largest export countries are Saudi Arabia, Iraq, and the USSR. The instability of oil supplies is caused by political problems associated with the major oil export countries.

The world oil market in the next two decades is likely to be dominated by OPEC. Except for Saudi Arabia and Iraq, Arab countries will produce oil only at that level necessary to finance internal economic development. Non-OPEC countries' production of oil will increase significantly, but most will be consumed internally.

Political and military intervention by the Soviet Union or its proxies in major oil exporting nations is probable within the next few decades.

Oil prices will increase more rapidly than other energy source prices because of the OPEC cartel control and the political instability of Arabian North African nations.

Oil will be a major energy source for the next two decades, because it has multiple uses and is easy to handle. Korea wants energy supplies which are secure with much supply and low-priced. At the current energy consumption rate in Korea, the oil utilization rate will be 93.2 percent in 2001. The oil dependency is dangerously high in the absence of internal reserves and associated production.

The Korean government has considered these difficulties and desires to implement an oil substitution plan.

Coal, gas, and nuclear energy are candidates for the interchangeable energy sources.

3. Gas

Natural gas accounts for 42 percent of world-wide petroleum (i.e., oil and gas) reserves. Furthermore, new reserve additions for gas have exceeded those for oil. Despite the magnitude of world natural gas reserves and the rate at which they are increasing, the role of gas in international energy trade is small. In 1978, total global gas trade was only 2.9 mbd which is one-twelth that of the oil trade. The majority of international gas trade was through pipelines, and LNG trade was only 1.4 percent of world oil trade.

The major reason for this disparity in the trade is the fact that gathering and transporting natural gas is more expensive.

Natural gas will not be available to Korea through pipelines from the USSR or China during the next two decades, therefore Korea will have to import LNG from the Persian Gulf and Indonesia. LNG is a poor alternative source for oil because the LNG price is higher than oil, and there is some probability of the effects of a gas exporting carte. However LNG provides some diversification in energy sources.

4. Nuclear Energy

Nuclear power is a significant potential energy source which could reduce Korean oil usage. After the mid 1950's,

the United States led the world in the construction of nuclear power plants. However, after the Three Mile Island accidents in 1979, nuclear power plant development slowed significantly. The oil crisis also encouraged the building of nuclear power plants by energy-poor nations. Examples are France, Japan, and Korea.

The Korean government desires to construct nuclear power plants at an increasing rate. According to the energy substitution plan for oil, the amount of nuclear power energy will be 43.29 MTOE or 13.9 percent of utilized energy rate in 2001. However, it is anticipated that nuclear power cannot replace much oil usage for the following reasons:

1. the possibility of a dangerous accident;
2. the air pollution problem;
3. the absence of a guarantee of economic advantage;
4. the policy of developed countries which opposes nuclear development.

5. Coal

World coal trade is expected to grow dramatically between 1982 and 2001. Coal exports are projected to increase 2.5 times between 1980 and 1990, and then grow by 2.5 times again between 1990 and 2000.

North America, Australia, and South Africa will be the major exporting areas. Since most of the Japanese imports will be from secure sources of supply, Korea can take advantage of this steam coal trade by obtaining supplies from the same sources as Japan.

The coal price increase will be much smaller than oil or LNG. Despite certain increases in coal prices, this fuel will become increasingly competitive with oil or LNG. The coal prices are estimated to be in the range of 20 to 30 percent of oil prices by 2001. Therefore, coal will be the best interchangeable energy source for oil.

B. THE IMPLICATIONS OF COAL AS THE BEST ALTERNATIVE SOURCE

1. General

In Korea, bituminous coal requirements will increase rapidly from 3.7 MTOE, or 8.4 percent of total energy utilized per year in 1981 to 87.7 MTOE, or 28.3 percent in 2001. Korea must import all the bituminous coal required, and also some hard coal to supplement domestic production. Questions of overseas transportation, port facilities, internal transportation, and import source must be considered.

2. More Coal and Less Oil

The forecasts of long-term energy requirements in Korea suggest that the oil requirements will increase rapidly and if these are correct, it is clear that Korean oil dependency will be too high. In 2001, oil requirements will be 289.2 MTOE, or 93.2 percent of the utilized rate. If the Korean government tried to reduce the oil dependency by using the substitution plan, then coal will be required minimally at the present utilized rate of about 35 percent. Using the final long-term energy requirements of Figure 24, hard coal requirements would increase very slowly from 11.6 MTOE in

1981 to 19.9 MTOE in 2001, but its utilization rate would decrease sharply from 26.4 percent in 1981 to 6.4 percent in 2001. Even though hard coal is the major domestic energy source in Korea, the hard coal production can't follow the increasing consumption rate, because of the limitation of domestic hard coal reserves and difficulties of production.

Bituminous coal requirements will increase from 3.6 MTOE, or 8.4 percent of utilized rate in 1981 to 87.7 MTOE, or 28.3 percent of utilized rate in 2001.

3. Transportation and Port Facility

There are no bituminous coal resereves in Korea, therefore it is necessary to import all bituminous coal and some hard coal to supplement domestic production. It is difficult to import this coal from China, Russia, North Korea by rail. Therefore, Korea should consider developing the means of overseas transportation, port facilities for unloading coal, and domestic transportation for distribution of coal to the users. Regarding the overseas transportation: Korea has two alternatives, first; utilize a foreign coal carrier, second; utilize a domestic coal carrier. The second alternative assumes that Korea can built large coal carriers with the present shipyard technical knowledge used currently to construct large oil carriers. Korea must expand the port facilities for unloading imported coal and develop more rail and road facilities for distributing the imported coal.

4. Sources of Imported Coal

Korea must seek foreign coal sources with a high security of supply and low price. North America, Australia, and South Africa are the most promising possibilities.

Korea should consider several options in order to achieve a secure supply at a low cost.

First, choose nearby nations in order to reduce the transportation costs.

Second, consider fostering improved diplomatic relationships with coal exporting countries.

Third, diversify the sources of imported coal.

Fourth, form joint ventures and long-term contracts to develop foreign coal.

In order to implement some of the above options, a group of experts and technicians must study those options. Korea can probably learn from Japan's efforts to seek a secure coal supply at low prices.

C. RECOMMENDATIONS

1. Oil

Oil will be the major energy source for the next several decades in Korea. Unfortunately, oil is a most unstable energy source. The following list gives several recommendations for addressing the problem:

1. Substitute other energy sources for oil as much as possible.
2. Diversify the sources of imported oil.

3. Arrange for the direct imporation of foreign oil.

4. Form joint capital ventures to help guarantee a long-term supply.

5. Increase explorations for oil deposits.

6. Continue offshore drilling.

7. Import more heavy crude oil and refine it domestically.

2. Coal

Coal imports must increase rapidly, because it is the most suitable substitute for oil. To implement this exchange several recommendations follow:

1. Form joint ventures and long-term contracts.

2. Construct overseas coal carriers in Korea.

3. Expand the port facilities, railroads, and highways for importing and distributing coal.

4. Import coal from at least two sources.

3. Gas

Gas offers a greater security of supply than oil. Even though the natural gas prices are competitive with oil prices, Korea does not expect the establishment of pipelines between Korea, China, and Russia. Under the conditions just described, two options for gas are recommended.

First; import LNG from two sources. LNG imports offer a greater security of supply than oil imports or natural gas imported through a pipeline. Although currently the LNG price is higher than both oil and natural gas prices, the price range will fall between the light and medium crude oil

prices over the long-term. Korea will import LNG from Alaska, Bangladesh, Nigeria, Indonesia, Australia, Malaysia, Trinidad, Columbia, and Chile. Indonesia, Malaysia, and Australia are probably the best sources of LNG because of geographical proximity.

Second; produce medium Btu gas (MBG) from imported coal. MBG production has a higher security of supply and a lower price than oil or LNG. However, an MBG production plant would require a large investment of capital. To build a plant which could produce 40,000 barrels of MBG per day would requie 1.6 billion dollars of investment capital. Successful implementation of this option depends on engineering and project management skills, and the availability of the necessary investment capital.

4. Nuclear Energy

Nuclear energy for industrial use started in the U.S.A. in the mid-1950's. Worldwide nuclear power energy production was 47.7 million KW in 1973 and 125.8 million KW in 1979. The oil crisis accelerated the development of nuclear power plants. Despite the Three Mile Island accident, strong feelings against nuclear development, and little guarantee of economic gain, energy-poor countries such as France, Japan, Italy, and West Germany wish to increase their nuclear energy production.

Two options for nuclear energy are recommended.

First; import nuclear power plants from two sources and include the uranium supply conditions in the plant import

contracts. Korea has to import uranium because of limited uranium reserves of poor quality. Many countries want to export nuclear power plants. Therefore it is likely that Korea can arrange a stable supply of uranium in conjunction with the importation of nuclear power plants. The three largest uranium-producing countries are the U.S.A., Canada, and South Africa, and these nations offer the best prospects for purchasing nuclear power plants.

Second; establish a Korean nuclear safety organization to deal with the dangers of nuclear power plants. Currently, nuclear energy production is not increasing at the rate which was initially planned. But, in the long-term, its production will increase more rapidly as other energy sources become more limited. The safe operation of nuclear power plants will ultimately be the most important Korean concern regarding nuclear energy.

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