

# Energy Policy Forum

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## Integrated National Energy Planning: A Case Study of the Republic of Korea

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### BACKGROUND

Like other oil-importing countries, the Republic of Korea was surprised by the rapid oil price escalation of the 1970s. Following the lead of the United States, Europe, and Japan, Korea's energy policy in the mid-1970s was based on reducing oil imports by substituting other fuels, installing more efficient oil conversion processes, or doing without. Due in part to the urgency of the situation and in part to a lack of accumulated analytical capability, it was difficult to analyze in depth which alternatives were best, how much they would cost, or to what extent it was in Korea's best interests to bear large economic costs to reduce oil imports. Rather, Korean policy-makers implemented a broad-based oil consumption reduction program to mitigate their immediate oil import problem.

By the late 1970s, Korea perceived that oil prices were unlikely to return to their pre-1973 levels and that most of the low-cost import reduction decisions had already been made. The Korean government now needed answers to such increasingly difficult and expensive questions as:

1. *How should Korea structure its oil consumption reduction program?* Some oil consumption reduction alternatives are likely to have a disproportionate

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effect on heavy refined products. Will particular alternatives achieve the desired goal of import reduction; will they merely impose large economic costs on domestic refiners to modify existing refinery configurations; or will they merely change the mix of crude and products imported without appreciably changing the aggregate quantity?

2. *Should the government modify its petroleum product pricing policy to change the pattern of demand for refined products?* In particular, should the government use the price system to entice the desired investment and consumption behavior?
3. *Should Korea continue its ambitious nuclear expansion program?* Which competing fuels will be displaced by nuclear energy? What is the cost of the displaced fuels relative to nuclear energy?
4. *Should the government continue to encourage coal use?* Should investments in coal import facilities be continued? Should coal use in industry be encouraged? Should coal prices to residential customers continue to be subsidized?
5. *Should Korea proceed with its proposed liquified natural gas (LNG) import facility?* Long-term contracts with Indonesia or others appeared to be economically attractive. Would such gas displace refined products? Subsidized coal? Could Korea realistically absorb the large quantity of gas anticipated? Would the gas be economical at the anticipated delivered price?

These and other policy questions are closely interrelated. Korean decision-makers recognized that they needed an integrated national energy planning capability, one that could generate consistent forecasts of a wide variety of government programs on many fuels, technologies, and sectors of the economy. Even though this paper focuses to a significant extent on Korea's oil consumption reduction questions, we will continually reemphasize the integrated nature of the underlying analytical tools and their ability to capture important interfuel and intersectoral interactions in Korea.

To meet Korea's integrated planning needs and the United States' interests in the developing country energy situation, a joint energy assessment program was begun in late 1979 as a cooperative effort between Korea and the United States.<sup>1</sup> Unlike more traditional energy assessments (based on largely uncoordinated mission reports), the Korean/U.S. energy assessment placed primary emphasis on the integrated treatment of a wide range of supply and demand sectors. Given this objective, an economic modeling language developed by Decision Focus Incorporated (DFI), called the Generalized

1. This was the Country Energy Assessment (CEA) program sponsored and administered by the United States Department of Energy (DOE). Technical program management was performed by Argonne National Laboratory. Participating Korean institutions included KAIST, MER (Ministry of Energy and Resources), and KIER (Korea Institute of Energy and Resources).

Equilibrium Modeling System (GEMS), was selected to support the Korean assessment. The model built using the GEMS came to be known as the Argonne Energy Model for Korea (AEM/Korea). Upon completion of the assessment project in 1981, the AEM/Korea model was transferred to Korea, where it has since been run to address various policy questions. The primary purpose of this paper is to summarize salient results from a number of studies conducted within Korea by MER, KIER, KAIST, and Yukong subsequent to the original Korean energy assessment. (See Ahn, Kim and Nam, 1983 and Ahn and Nam, 1983.) These studies embody a large number of model and data improvements over the AEM/Korea model, and a common underlying theme has been to evaluate real-world policy issues that involve many fuels, sectors, and projects.<sup>2</sup>

The paper is organized as follows. The second section describes the methodology underlying the Korean energy model. The third section describes the results of Korea's integrated planning studies and discusses their implications for government and private investment and pricing decisions. The last section concludes by summarizing the Korean experience and extrapolating it to other countries.

## STRUCTURE OF THE KOREAN ENERGY MODEL

The Korean energy model determines equilibrium prices and production levels for all energy products from primary resources through end-use services. Figure 1 shows the interrelationships among sectors in the model. Each box in this figure represents a sector of the Korean economy and each link represents a flow of energy products between sectors. At the bottom of this network are nine fuels imported by Korea: nuclear fuel, crude oil, anthracite and bituminous coal, LNG, naphtha, distillate, residual, and LPG. Associated with each of these imported fuels is an exogenously entered projection of prices over time. The three supply sectors (gas, oil, and coal) represent the transportation and potential supply level conversion of primary fuels (e.g., coal gasification). The electricity sector represents the production of electricity from delivered fuels. The distribution sector takes in each of the transported fuels (including electricity) and distributes them among the various demand sectors. Four demand sectors are included in the model: residential/commercial, industry, transportation, and public.

Within each sector in Figure 1, a subnetwork of process submodels defines the interactions among agents and markets in that sector. For example, Figure 2 shows the subnetwork in the industry end-use sector. The topmost

2. To avoid confusion, we will call the enhanced version of the AEM/Korea model the Korean energy model.

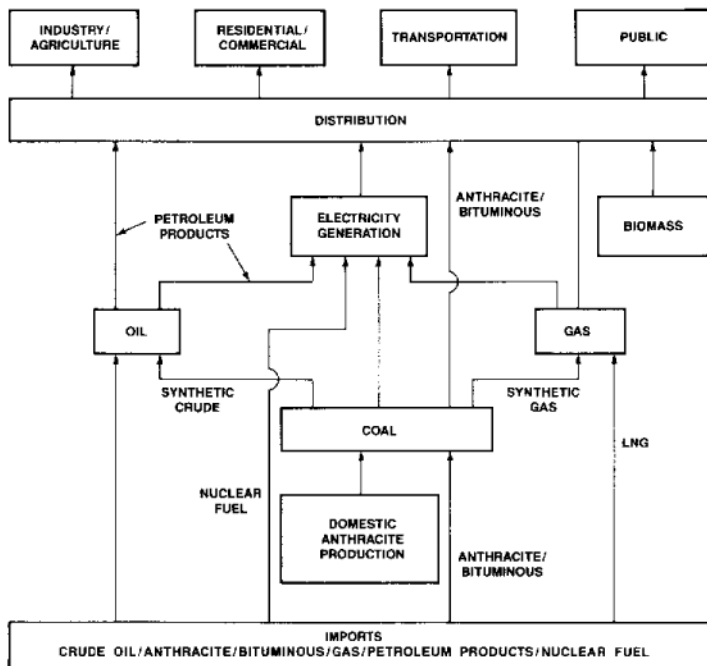


Figure 1. Interrelationships among energy subsectors.

row of circular processes in the figure represents the demand for each industrial product. The next lower row of circular processes represents the forms of end-use energy necessary to produce those industrial products (e.g., steam, direct heat). Competition among alternative technologies to produce the end-use energy forms is represented by the many boxes below these circles with arrows pointing into the circles. Competition among these boxes, each of which is associated with a particular fuel, determines the proportions of delivered fuels. In the model, competition among energy delivery technologies (and thereby competition among fuels) is assumed to depend on the relative economics of those technologies and of the fuels they consume. The industrial sector in the Korea model is quite disaggregated in order to make important distinctions among energy-intensive manufacturing industries, since Korean industry is expected to undergo significant structural changes.

The complete network representation of the Korean energy system and the accompanying numerical inputs are presented in Office of International Energy Programs (1981). Descriptions of the mathematical relationships used within each process, the iterative method used to solve for supply-demand equilibrium in the model, and the mathematical interpretation of the

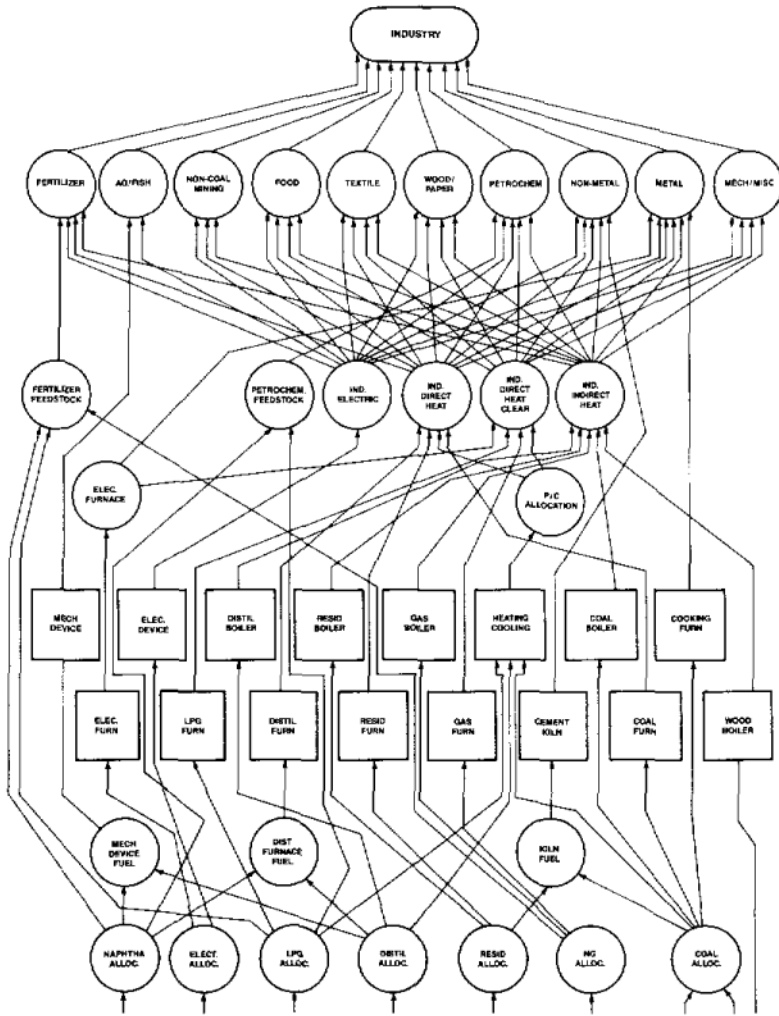


Figure 2. Industrial sector subnetwork.

solution can be found in Decision Focus Inc. (1983) and Adler, Cazalet, Haas, Marshalla, Nesbitt, and Phillips (1979).

In the Korea model, the demand and distribution sector subnetworks are more detailed than the supply sector subnetworks. This reflects the fact that Korea's major energy-related decisions concern demand and distribution rather than primary resource supply. The need for relatively more detail in the demand sectors is typical of so-called pipeline economies such as Korea or Japan in contrast to countries such as the United States, Australia, or Argentina that are richer in primary resources.

## KOREAN ENERGY PICTURE—NOW AND THE NEXT TWO DECADES

### Current Energy Situation in Korea—Active Oil Consumption Reduction Programs

In 1981 crude oil (imported mainly from east Asia) constituted almost 60 percent of Korea's primary energy requirements. In 1981 alone Korea's total crude import bill reached about \$6.2 billion (US), about 32 percent of the nation's total import bill. Korea's degree of dependence on outside resources presages the magnitude of potential impacts of crude oil price changes upon the nation's economy.

Korea's vulnerability to imported energy availability and price changes has driven its policymakers to adopt reduction of oil dependence as their top priority. For example, Korea Electric Power Company (KEPCO) has already constructed three nuclear reactors (1,900 MW total), and six more are under construction (900 to 1,200 MW each). All are expected to come on line by 1991. KEPCO will bring on line an additional 2,120 MW of bituminous coal-fired plants within five years and expects to convert several oil-fired plants to coal during the 1980s. Coal and nuclear fuel are expected to constitute over 69 percent of total electric production by 1991, all but eliminating the need for oil-fired plants. Moreover, Korea recently has signed a long-term contract for two million tons per year of LNG from Indonesia (beginning in 1987). Part of this LNG will be used for gas-fired baseload generation.

Based on KEPCO's long-term projection, the share of electric generation from oil will be drastically reduced—from 70 percent to 1981 to approximately 19 percent in 1991. Considering that the electric sector has until now consumed about half of all domestically refined bunker-C, KEPCO's ambitious nonoil expansion program will have serious impacts upon the nation's refiners and other fossil fuel suppliers, particularly because the reduction in oil consumption in the electric sector will not affect all oil products uniformly—it will affect primarily a particular refined product (bunker-C).

In the industrial sector, the majority of energy consumed is in the form of petroleum products, particularly heavy fuel oil for process heat and steam generation. Policymakers see ample room for interfuel substitution, particularly with coal. In the direct-heat market (excluding the iron and steel industry), bunker-C oil accounts for about half, light oil products supply about 40 percent, and the remaining 10 percent is supplied by anthracite coal. Even though there might be some technical restrictions affecting substitution by coal due to the temperature level or cleanliness required for some types of furnaces, significant opportunities exist for coal substitution.

The government maintains an active role with regard to medium- and large-size boilers using heavy fuel oil. In 1981 about 92 percent of the fuel

consumed for process steam generation was bunker-C. Recognizing the substitution possibilities, four coal import centers (port facilities) are being constructed near Inchon, Mokpo, Ulsan, and Bookpyong, and low interest government loans are being offered as incentives to induce a shift to coal boilers. However, this policy may not reduce total energy imports, since both coal and oil currently are imported. Nevertheless, the policy will induce shifts from one form of imported energy (oil) to another (coal), thereby diversifying Korea's fuel supply.

Turning to the demand side of the energy system, the main fuel for space heating has been domestically produced anthracite coal, which accounts for over 60 percent of all fuels delivered to the household/commercial sector. This anthracite coal (which is processed into briquettes) is used to heat the furnace holes of ondol floors for cooking and space heating in residences that are so equipped and, more recently, to fire boilers for space heating. However, widespread coal burning has proven hazardous and inconvenient. As living standards continue to increase, higher-income groups are expected to shift toward cleaner and more convenient fuels. Coincident with the Indonesian LNG import decision, the government is drawing up plans to encourage residential/commercial gas consumption, including the construction of gas pipelines around metropolitan areas.

As of 1981, gasoline consumption for small cars accounted for 12 percent of total sector consumption, distillates including diesel fuel and jet fuel constituted 74 percent, and heavy bunker oils for maritime use represented about 10 percent. A transportation fuel of critical concern is diesel fuel. Traditional consumers of diesel are intra- and intercity buses and freight trucks, whose activity levels are directly linked to overall economic growth. Recently, with apparent stimulus from the low price of distillate relative to gasoline,<sup>3</sup> an increasing number of diesel-powered passenger cars have entered the market. Diesel-powered Bongo vans introduced a few years ago have shown almost explosive market penetration in the passenger service market.

In summary, current policy directions to reduce imported oil dependence are likely to reduce the consumption of bunker-C, but not necessarily of other oil products. It is also likely that the demand for distillate products will increase (particularly in the transportation sector) unless significant energy efficiency improvements for distillate-based technologies can be achieved. Unless the nation's refinery industry can be made flexible enough to meet anticipated demand pattern changes, Korea can expect to experience worsening supply-demand imbalances among oil products.

Clearly, effective policy solutions for the oil product markets are not held solely by refiners but are also held in a very diverse fashion throughout the entire Korean energy system. The nonpetroleum electric expansion program

3. Recall that gasoline is heavily taxed under current government policy.

or the Indonesian LNG import option must be evaluated with due consideration of secondary effects upon the rest of the energy system, in particular on the oil sector. It is clear why an integrated analysis and an accompanying integrating model is needed. The remainder of this paper attempts to project the evolution of Korea's energy system through 2001, to reevaluate the current oil dependence program, and to review the resulting policy implications inside and outside the oil sector.

### **Korean Energy Future for the Next Two Decades: Integrated Analysis**

**Key Reference Case Assumptions.** This section summarizes the key economic and technical assumptions used to define a reference case or *baseline* for the network described in the second section. We do not attempt to completely describe every model input, only to summarize the highlights.

The model spans the time horizon 1981–2001 in five-year intervals. Major inputs to the model include end-use projections for each consuming sector throughout the study period, primary and imported energy price paths, and cost and performance estimates for every technology in the network. Economic growth assumptions and anticipated industry structural changes needed to project end-use energy consumption were derived from the Korean Economic Planning Board's (EPB's) preliminary study results for the nation's economic development picture for the next twenty years (Korea Development Institute, 1985). In the EPB study, annual GNP growth rates for the next twenty years are estimated to be about 6.5 to 7.5 percent, whereas the manufacturing sector is assumed to grow slightly more rapidly at 8.5 to 9.5 percent. The implied high growth rate in the energy/GNP ratio is based on an assumption that a major restructuring of Korean industry will occur over the next twenty years. In particular, it is expected that less energy-intensive but high value-added industries (e.g., high-technology or information-intensive industries such as precision machines, electronic equipment, and service industries) will continue to grow faster for the next two decades than the traditional heavy industries. This trend has been observed in recent government planning statistics, and is projected to continue over the study horizon.

Imported crude and LNG prices are assumed for the reference case to decrease at a real rate of 3 percent through 1985, to increase at 2 percent real through 1991, and to increase at 4 percent real thereafter. Imported coal prices are assumed to remain constant until 1985 and to increase at 1 percent real annually thereafter. The coal price assumption is based on the perception that international coal market prices will be determined based primarily on the long-run marginal cost of production with minimal economic rent.

In the residential/commercial sector, all new apartment buildings are assumed to be heavily insulated and half of all new single family dwelling

units are assumed to be insulated according to the current stringent housing insulation act of the MER. Even though electric space heating is not economical today, it is assumed to be one of many competing residential and commercial heating sources in the future.

In the industrial sector LNG is precluded from use in petrochemical plants but allowed in fertilizer processes. Naphtha and LPG are assumed to compete as feedstocks for nonfertilizer petrochemical plants. In light of recent government actions to shut down excess fertilizer plant capacity, total fertilizer production is assumed to remain constant. New cement kilns are assumed to use bituminous coal rather than heavy fuel oil, reflecting prevailing industry trends.

On the supply side, it is assumed that policymakers will act to eliminate existing oil-fired plants from baseload operations and to preclude the addition of new oil-fired units. Since LNG imports from Indonesia will be based on take or pay contracts beginning in 1987, the entire contracted quantity must be absorbed into the domestic market. To analyze what will happen to other fuels, the model forces this gas into the energy system and measures resultant shifts in other fuels.

Regarding the price paths of delivered fuels, particularly those under regulation, it is assumed that the government's currently planned decontrol of prices will occur within the next decade. Electricity rates will continue to be set based on cost. These cost-based rates (which are endogenously estimated within the model) will decrease as nuclear increases its share of the market. The pricing structure of oil products is assumed to converge by 1991 to that of the Singapore spot market. (Such a pricing structure can be sustained via excise tax adjustments.)

**Energy Demand and Supply in the Next Two Decades.** In determining the baseline future energy supply-demand picture, the model selects from among all competing fuels and technologies to satisfy the specified end-use demands based on the existing fuel supply configuration, the rate at which new technologies can be introduced, potential improvements in efficiency resulting from new technologies, responsiveness of the market to relative energy prices, and a number of other parameters.

With regard to primary energy inputs to the economy, Korea will continue to rely on imported oil as a swing fuel for the next twenty years but at a reduced fraction of total primary energy consumption—down from 59 percent in 1981, to 44 percent in 1991, and 38 percent in 2001. This reduction in oil dependence will be due mainly to displacements by nuclear, coal, and LNG (see Figure 3). Our results imply a somewhat higher degree of oil dependence than some policymakers expect or, stated more correctly, than policymakers expected in the absence of integrated analysis. Our integrated analysis has confirmed the existence of potential bottlenecks within

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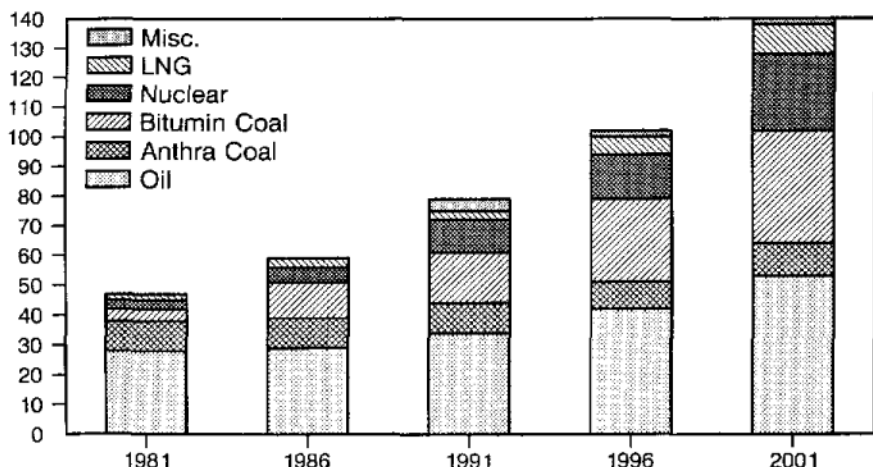


Figure 3. Korea's primary energy consumption: 1981–2001.

the system that work against the ambitious oil consumption reduction programs.

Looking in more detail at the residential/commercial sector, Figure 4 shows that the future role of anthracite coal briquettes (which currently dominate the sector) will diminish. By 2001 the share of anthracite coal in the residential/commercial sector will decline to 35 percent from its current level of 62 percent. Electricity use shows the most rapid increase over the model horizon. Interestingly, electricity does not promise to be particularly competitive in space-heating and cooking markets. The reason is that electricity prices do not fall rapidly enough to compete with subsidized anthracite coal, even though the conversion efficiency of electricity is much higher. If anthracite coal prices were decontrolled (i.e., if all subsidies were eliminated), LNG and electricity consumption for space heating would increase markedly. However, Korean energy policymakers do not feel comfortable with such decontrol. This is because of the risk that domestic coal consumption will decline precipitously, directly contradicting high-level government policy directives that emphasize maximum utilization of domestic resources and avoidance of higher costs to low-income people who rely on coal briquettes.

Figure 5 depicts industrial sector consumption and indicates that bituminous coal will replace bunker-C oil as a major industrial energy source. By 2001 the share of coal in the industrial sector can be expected to rise to 53 percent. The future will see strong competition between coal and heavy fuel oil in direct-heat markets. This competition will see the share of bunker-C oil drop

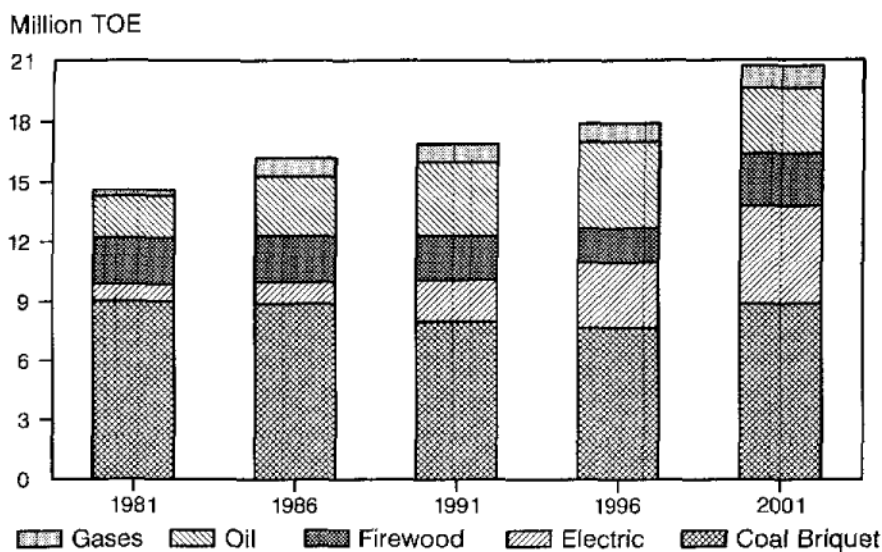


Figure 4. Fuel consumption in the residential/commercial sector: 1981–2001.

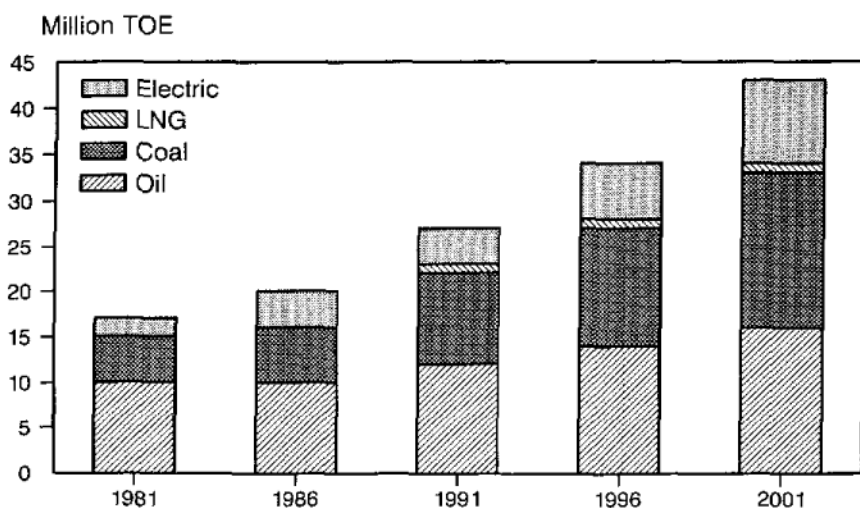
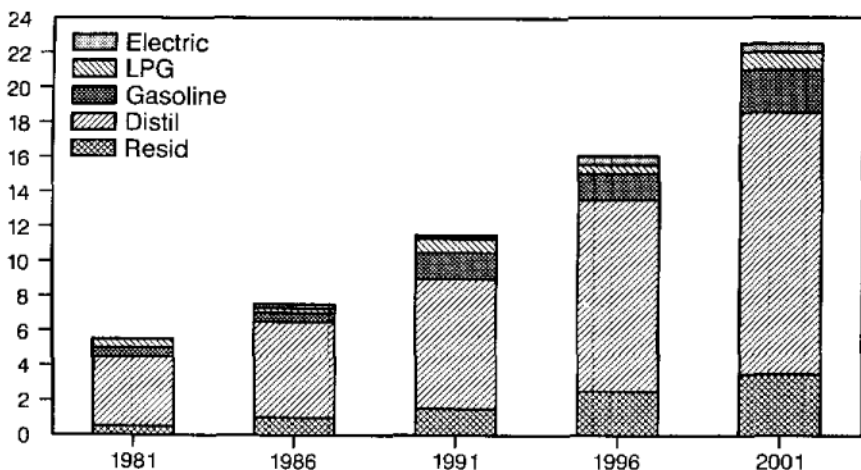


Figure 5. Fuel consumption in the industrial sector: 1981–2001.

substantially from its current level of 34 percent. The market share of electricity increases gradually from 12 percent in 1981 to 19.5 percent in 2001. Electricity cost remains relatively high and electricity does not displace other fuels. Rather, the demand increase results from the expected restructuring of

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**Figure 6. Transportation fuel consumption 1981–2001.**

Korean industry toward precision and high-technology industries (which typically are electricity-intensive).

As shown in Figure 6, more than 99 percent of all transportation demands are currently satisfied by oil products. Transportation sector fuel demand is projected to grow by more than 7 percent annually over the next twenty years. Distillate, primarily in the form of diesel fuel, will continue as the dominant fuel in the sector and, in fact, it is one of the most strategically significant fuels in Korea—it is a virtually nonsubstitutable fuel for buses and trucks and directly influences the amount of oil imported. Distillate consumed is projected to increase fourfold in the next twenty years.

In the electric sector, major structural changes in the generation facility mix are forecast by the model (see Figure 7). Oil-fired generation, which currently constitutes more than 75 percent of total generation, will drop—decreasing to 18.8 percent by 1991 and to only 6.6 percent by 2001. This rather drastic reduction of oil for electric generation will create a rather serious structural problem for fossil energy suppliers, since until now about half the domestically refined bunker-C oil has been consumed in electric generation. Meanwhile, nuclear power will enter the generation mix in a dramatic way, becoming the number one power source by 1991. Its share of total generation at that time will be 49 percent, and the model projects more than 43 percent of the nation's generation requirements in 2001 will be satisfied by nuclear generation. Coal will join nuclear as a major baseload source—almost 40 percent by 2001. As discussed earlier, construction of LNG-fired generation capacity may be undertaken in order to ensure that Korea will absorb the entire

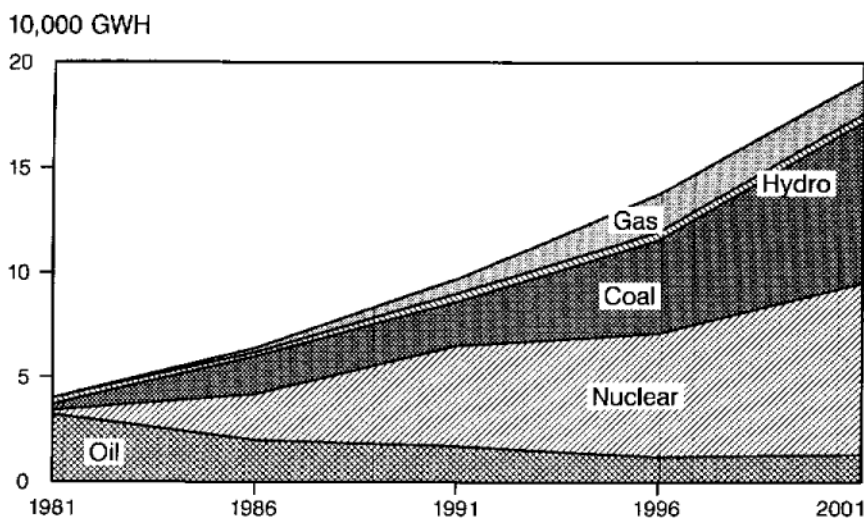


Figure 7. Future power generation mix: 1981–2001.

contracted amount from Indonesia. This decision is not motivated by the economics of gas-fired electric generation; indeed, gas is not economically competitive with coal and nuclear for baseload generation. The share of gas in the long run is expected to grow from 3.5 to 13 percent between now and 2001.

Figure 7 indicates that a major portion of electric generation in Korea will be from coal and/or nuclear sources. Given the present uncertainty in relative (and absolute) coal and nuclear generation economics, it is extremely difficult to know the optimal expansion plan today. It is probably most appropriate to interpret the figure as indicating the need for substantial baseload capacity expansion—coal and nuclear—with the specific mix to be determined by more detailed, sector-specific analyses (KEPCO frequently conducts such analyses). Regardless of how such analyses (and the resulting investment strategy) turns out, nuclear generation will be large enough so that Korea will have to consider indigenous uranium mining capability, the stability of import sources, plant security, and environmental effects of fuel processing and waste disposal. Stability of import sources and the environmental effects of coal combustion and waste disposal must also be considered, particularly under our projected generation mix.

Korea's coal sector (including domestic and imported anthracite and bituminous coals) will undergo dramatic changes. Domestic anthracite production is limited by resource availability and shows a declining trend over the twenty-year planning period. Of concern to policymakers is the possible decline in household sector demand even at the subsidized price,

which would reduce revenues to coal miners and briquette manufacturers. By contrast, production of bituminous coal for electric generation is expected to grow rapidly. Increased use of bituminous coal for electric generation and industrial process heat and steam generation will require significant infrastructure expansion to handle the increased volume—new port facilities, coal handling equipment, and reliable distribution/transportation networks.

Korea's Indonesian LNG policy grew out of two policy needs perceived by the government: (1) the need to diversify Korea's sources of supply and (2) the desire to increase the use of gaseous fuels in the residential and commercial sectors. Much of the imported LNG will be distributed to households and industries mainly in the Seoul-Inchon area, with the remainder going to electric generation. It is expected that about six million tons of LNG will be needed by 2001, three times the 1987 import amount.

The reference case assumes that the entire cost of gas, including the distribution cost, will be borne by end-users. If distribution costs were subsidized, however, gas penetration would be stimulated further in the household sector. Potential subsidization of gas distribution is a complex issue, however, because subsidized gas would compete directly with anthracite coal, which itself is subsidized. This would put Korea in a situation in which the government would be subsidizing one fuel (gas) to make it more competitive with another subsidized fuel (anthracite briquettes). The net result would be a general subsidy of residential/commercial energy consumption, which might unduly discourage conservation and lead to significant economic efficiency losses.

To avoid the problem of competing subsidies, Korean policymakers must either eliminate the subsidy on anthracite coal briquettes and allow LNG to compete on a nonsubsidized basis or let LNG compete without subsidy against subsidized coal. The latter scenario implies that LNG will not be able to penetrate the space-heating market to the extent desired. That is, residential/commercial consumption of LNG will fall short of policymakers' goals. This will force relatively more LNG to be piped to power plants, replacing some of the current bunker-C fuel, which in turn will further aggravate the oil product imbalance situation. In our reference case, LNG demand growth is rather moderate, constituting less than 6 percent of the nation's total energy needs, even by the year 2001.

**Future Oil Dependence.** We have emphasized that oil dependence reduction is one of Korea's major energy policy goals. Opportunities to replace oil with other fuels and thereby reduce oil dependence are actively being sought. This seemingly obvious policy direction, however, could be expensive due to the particular nature of these oil reduction schemes and the inherent structural rigidity of Korea's existing refineries.

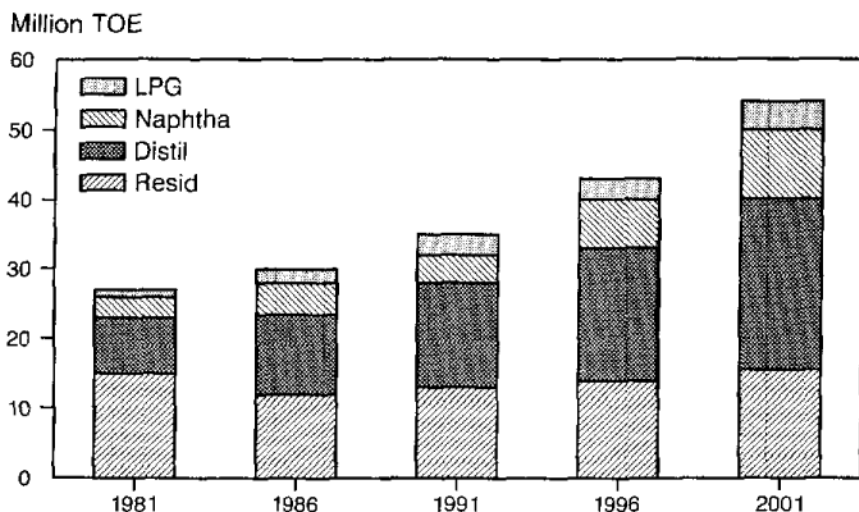


Figure 8. Oil product demand pattern: 1981-2001.

Figure 8 shows the expected oil product demand pattern for the next twenty years as determined by the Korea energy model. The figure indicates a shift away from residual oil toward distillate. In 1981 residual oil comprised more than half of Korea's total oil product consumption (56 percent), while distillate comprised less than 30 percent. The model indicates a very marked shift from Korea's traditionally resid-based consumption pattern to a distillate-based pattern. As shown in the figure, distillate consumption grows from a 29.4 percent share of the oil product market in 1981 to 41.2 percent in 1991, and 47 percent in 2001. By contrast, resid consumption falls from 56 percent in 1981 to 37 percent in 1991, and ultimately to 29.5 percent in 2001. In effect, distillate and resid can be expected to trade places in the oil product consumption mix, all other products maintaining relatively constant market shares.

As mentioned previously, these dramatic changes in the demand pattern for refined products result primarily from increased demand for distillate fuels in the transportation sector (particularly in inter- and intracity passenger buses, diesel powered freight trucks, and jet aircraft) and more importantly, from the displacement of residual oil by nuclear, coal, and LNG in the electric sector and by bituminous coal in industrial steam and process heat markets.

As these changes occur, oil supply inflexibilities are likely to be exacerbated further. We anticipate heavier and higher sulfur crude will become increasingly available in Korea (and the rest of the world). OPEC suppliers upon which Korea relies are projected to offer increasingly heavy, high-sulfur

crude. If refined in Korean refineries without heavy oil upgrading, heavier crudes will yield a relatively higher proportion of heavy oil and thus will exacerbate the heavy-light product imbalance.

Given the current world mix of refineries (containing many distillation-only facilities) and the continued and perhaps growing importance of middle and light products in world markets, one can argue convincingly that resid will be in abundant supply on world markets in the longer term. If this occurs, resid prices will be low relative to those of light and medium products. Countries trying to export resid into such markets will find that their product generates little revenue.

This assertion, counter to recent price fluctuations that have seen resid and crude prices close, bears further examination. In view of the present mix and extent of world refinery capacity (the world industry may be operating as low as 65 percent capacity today), there is tremendous capacity to produce heavy products as well as light and medium products at current prices. Substitution for heavy oil is relatively much easier than for lighter products, implying that demand for heavy oil is much more price-elastic. Our information for Korea, the United States, and elsewhere suggests that longer-term light-product prices will be set by modern refineries that produce little or no resid and that topping refineries will not be able to achieve adequate margins because of price-elasticity in resid markets. Therefore, they will either have to modernize or become noncompetitive. If the latter happens in Korea, the government would have to adopt subsidies to shield domestic refiners from world product prices—a potentially significant deadweight economic efficiency loss to the economy.

We take issue with the assertion that from a world refinery capacity perspective, one should never invest more in an industry that is already over capacity. On the contrary, competition ultimately will cull out more of the small, inefficient, nonmodernized producers in an industry that is over capacity. Those who wish to remain competitive must strive even harder.

Without undertaking comprehensive structural supply-demand measures in an integrated manner, Korea can expect to experience an abundance of residual oil and a scarcity of other oil products, including LPG, naphtha, and distillates. Assuming an optimal (i.e., cost-minimizing) level of crude imports and assuming that current Korean refinery configurations are held constant throughout the study horizon, residual oil production would be 30 percent greater than domestic demand in 1991 and 66 percent greater in excess of 2001. Under these same assumptions, distillate production would be 19 percent below domestic demand in 1991 and 27 percent below in 2001. Our results suggest that the high degree of imbalance under this scenario might well be modest compared to what could occur if current piecemeal import reduction programs were in force over the entire twenty-year study horizon.

The supply-demand equilibrium computed by the Korea model represents competition among the following alternatives: (1) retrofitting current refineries with cracking or coking capacity; (2) building new refineries with or without cracking or coking capability; or (3) importing finished light products. Even though the absolute level of residual oil demand in Figure 8 does not increase over time, the reference case model run suggests that it is economical to install cracking and resid conversion facilities in some existing refineries. To meet future distillate demand, the model estimates it is economical to add the following levels of heavy oil cracking capability: 85,000 barrels per day on a feedstock basis by 1986, 150,000 barrels per day by 1991, and 365,000 barrels per day by 2001. If this degree of refinery retrofitting occurred, the resulting cracker ratio (cracking capacity divided by total distillation unit capacity) would be 16 percent in 1986, 23 percent in 1991, and 37 percent in 2001. This degree of refinery modernization, although significant in terms of the fraction of total capacity retrofitted, is certainly well within the range of practicability—less than 40 percent of the distillation capacity in Korea would be involved. Also, retrofitting of existing refineries offers an additional advantage—it hedges against the possibility that future growth will be slower than that assumed in the reference case. On the other hand, considering the high cost, long lead time, and technical sophistication of installing cracking equipment in Korean refineries, Korean policymakers face the question of whether some of the existing or proposed oil consumption reduction alternatives should be slowed or eliminated. That is, by how much does the additional cost borne by the refinery industry offset the benefits of the oil import reduction program? Our integrated analysis provides an answer: the additional cost to the refinery industry is large but not prohibitive, and some degree of retrofitting is in the national interest.

### **Policy Implications for Smoother Transition**

This analysis has pointed out several issues of concern about the effectiveness and cost of various proposed oil consumption reduction alternatives. With the background of the previous sections, we now offer several new policy directions designed to facilitate a transition to a less oil dependent and reasonably diversified energy picture for Korea.

**Reevaluation of the Electric Sector Expansion Program.** The expected drastic decrease in oil-fired power generation will severely exacerbate the oil product imbalance problem. KEPCO's aggressive conversion to alternative fuels should be reviewed. Plants already under construction surely will have to be brought on line because of the already significant commitment of resources, but plants only in the planning stages should be subjected to extensive reevaluation, particularly in terms of timing. Indeed, it may

be prudent to postpone any new capacity or to otherwise adjust the specifications of any new plants so that they do not create major difficulties in other sectors. Even the four coal plants now being completed might best be operated as a hedge against the possibility that the excess resid cannot be profitably sold on spot markets.

**Oil versus Coal in Industry.** Korean policymakers should reevaluate the expanded use of coal in process heat markets. They should consider explicitly the total cost to the energy system of doing so, including the cost of the coal itself, coal import center construction costs, setup cost of the downstream distribution network for steady and stable supply, environmental costs (for ash and waste treatments), and additional investment costs indirectly imposed on other subsectors such as cracking costs in the refinery sector.

Because of the significant near- and medium-term committed capacity, the Korean supply-demand situation will be more affected by coal-oil interactions in the medium term than in the long term. In other words, Korea's recent decisions already have guaranteed that significant coal-for-oil substitution will indeed take place. In view of our reference case finding that long-run coal-for-oil substitution might not be as cost-effective as thought, Korean policymakers should seriously consider delaying any coal-for-oil measures not economic on their own merit without government support. This postponement period might be used profitably to pursue R&D activities for ash and waste treatment, new combustion technologies, and further economic evaluation.

**Restructuring Oil Product Demands in the Transportation Sector.** In view of the increasing requirement for distillate in the economy, any measure to reduce distillate demand or shift it to heavy oil demand will ease pressure on the supply industry and simultaneously reduce oil dependence. For example, fuels for buses and freight trucks (major distillate consumers) must be used effectively (i.e., conserved). This might involve establishing strict fuel efficiency standards on these vehicles and implementing more efficient passenger and freight transportation routing and containerization. As a second example, a larger portion of land-freight transportation based on distillate could be shifted to coastal shipping, which at present is based on residual oil. Such actions would directly ease the oil product imbalance.

**Modernization of the Refining Sector.** There currently is no heavy resid cracking facility in Korea; therefore, the ability to meet changing product demand slates is fairly limited. The only immediate solution to this resid/distillate imbalance is to import distillate and export resid.

Given the present refinery situation, several options must be considered: (1) No future expansion of the Korean refinery industry, in which case

refiners could continue to meet residual oil demand but could not meet distillate demand. Distillate would have to be imported; (2) installation of new distillation-only refinery capacity to the level at which domestic distillate demand can just be met, with excess resid being sold on the world market; (3) installation of new refineries with cokers and crackers that produce no resid to meet all demand growth, with existing refineries continuing to operate at present levels without retrofit; (4) retrofit of existing refineries with heavy oil conversion facilities, and either new refineries could be built or a range of finished products could be imported to meet any demand shortfall. (The reference case model run indicates that the fourth option is the most economical.)

The first option merely shifts Korea's dependence from crude oil to distillate, netting zero import reduction benefit. The second exposes Korean refiners to world resid markets (into which they must export) but not necessarily to world distillate and gasoline markets. Their margins will be squeezed, and they would bear the entire cost of the oil consumption reduction programs. In particular, if domestic light product prices were too low, they would go broke, and if they were too high, they would retrofit en masse. The third option would require installation of new state-of-the-art refining capacity, complete with crackers and cokers, on new sites. This is a risky strategy given the excess of world refinery capacity. By contrast, the fourth would allow new refinery construction to be delayed somewhat because the existing refinery mix could be adapted for a few years to the changing product demand slate. In particular, residual oil (now in excess supply in Korea) could be cracked to produce distillate (now in short supply), thus delaying for a few years the need for any new refinery capacity (or finished product imports if the capacity is not built) and delaying increased distillate imports. The model tells us that this delay pays benefits to Korea.

Thus, the integrated model tells us that refined product imbalances can be mitigated partially through prudent revision of policies outside the refinery sector, that is, through readjustment of particular oil consumption reduction alternatives. The model also tells us, however, that the imbalance cannot be rectified entirely without installing some heavy oil cracking equipment; policy shifts are not enough.

To retrofit Korean refineries with heavy oil cracking equipment will require careful planning. Choice of the right configuration of heavy oil crackers is very important and requires knowledge of the particular distillation units to which they are to be added and the particular demand pattern to be met. Also, anticipating the imposition of more stringent environmental regulations requiring the expanded use of low-sulfur products, candidate crackers should include hydrotreatment. Desirable processes would also have high distillate yields because of the anticipated market shift toward distillate fuels.

In addition, a proper oil product pricing structure with sufficient price differentials between distillates and residuals is needed to motivate private refiners to invest in facility modernization. To better reflect market forces in price setting and to induce a price structure to motivate the refiners' additional investments, the current rigid price controls should be eliminated gradually for competitive oil products such as residual fuels, gasoline, and kerosene.

**Key Uncertainties.** The analysis presented thus far is based on a single run of the Korea energy model—a reference case. For brevity, we will not present sensitivity analyses but will discuss two key uncertainties: world oil price and Korean demand.

A number of oil price sensitivity analyses have been run and, as expected, future oil prices are crucial to Korea. In higher oil price cases, the oil consumption reduction programs analyzed here are more beneficial than in the reference case, even though Korea is much worse off. That is, the mitigating effects of oil consumption reduction are much larger in high-oil-price cases, but Korea's economic situation will be severely threatened.

By contrast, in lower-oil-price cases, the oil import reduction programs analyzed here are much less valuable and indeed impose substantial costs on the Korean energy system. That is, low future oil prices would be highly beneficial to a pipeline economy such as Korea, but some of these benefits would be foregone if noneconomic oil import reduction programs remain in effect. Korean decisionmakers must carefully monitor the world oil situation and adjust their policies accordingly—rigid policies are not desirable. An optimal oil consumption policy is one that provides insurance for bad outcomes (i.e., high oil prices) but is not so costly that it erases the benefits in case of good outcomes (i.e., low oil prices). Aversion to risk by Korean decisionmakers would argue for more insurance but probably not to the degree contained in the current oil consumption reduction policies.

Equally important is the question of demand growth. Conceptually, high demand growth means that new sources of supply such as the LNG contract and the aggressive nuclear program are more likely to be absorbed into the economy. In particular, if demand growth is high, excess LNG will not have to be burned in the electric generation sector. Markets can be found for resid from currently existing refineries without retrofitting. Markets can be found for the electricity from committed nuclear plants. New state-of-the-art capacity is being added to the economy, which tends to be more flexible and more adapted to current world energy realities. In a world of high growth, therefore, Korea bears a relatively smaller risk from oil import reduction policy mistakes.

On the other hand, if demand growth is lower than in the reference case, the risk from oil import reduction policy mistakes are magnified. In particular, neither the Indonesian LNG nor the new nuclear plants will be fully

absorbed; in fact, they will compete against each other. Without major refinery retrofits and/or much less ambitious heavy oil reduction policies, Korea is likely to be awash in resid, eroding refiners' margins and discouraging new investment. It seems clear that limited modernization of refineries hedges in part against the possibility that demand growth will be slower than expected. These and other uncertainties currently are being examined in more detail.

## CONCLUSIONS AND SUMMARY

This paper has presented the results of a long-term analysis of the Korean energy situation, with particular emphasis on the effects of government policies aimed at reducing oil imports. Such policies include an ambitious nuclear and coal power expansion program, long-term contracting to obtain Indonesian LNG, and a set of subsidies, taxes, and quotas designed to reduce oil consumption in the demand sectors. The purpose of this analysis was to trace the effects of these policies through the Korean energy system in a consistent fashion. This was done using an integrated energy model that represented the effects of government policies on all technologies, fuels, and resources in Korea.

One of the major conclusions of this analysis is that, when viewed in an integrated fashion, the current set of government actions undertaken in Korea to reduce oil imports may be more expensive and less effective than previously realized. The reasons arise from the interactions of the various actors at different points in the energy system. For example, if current policies are continued, demand for distillate fuels will increase from 30 percent of refinery output to 50 percent, whereas residual demand will decrease from 50 percent to 30 percent by the turn of the century. Unless expensive refinery retrofitting is undertaken, Korea will either have to import distillate fuel, export residual, or both. Either situation would involve added imports of oil, either as distillate or as refinery feedstock.

This analysis suggests that a more balanced policy for oil import reductions that considers interactions of various factors might lead to equal or greater reductions in oil imports at a lower long-run cost compared to extending existing policies. Such a policy might forestall some planned expansion in baseload electricity generation capacity and concentrate on conserving fuels (mainly distillates) in the transportation sector, for example.

Many of the energy-related policy issues Korea faces are also faced by other industrializing nations. In particular, extreme dependence on imported oil is common to the Far East industrializing nations (Taiwan, for example), as well as most developing countries. Most, if not all, of these countries have instituted national energy policies the major goal of which is to reduce oil

imports. As this analysis has shown, broad-based government policies for reducing oil imports can have many unanticipated costs and undesirable effects resulting from the interaction of different government actions at different parts of the energy system. Without some type of integrated framework to capture these interactions, serious and costly imbalances can arise from a seemingly innocuous set of actions.

This case study of Korea demonstrates that government policy directives often lead to resource allocations that are not economically efficient—government policymakers cannot hope to outperform the price system from an economic efficiency point of view. Furthermore, this case study indicates that government-induced inefficiencies can be quite costly. Realizing this, free market economists might argue in the case of Korea (and other countries for that matter) that the government should not interfere in the energy system. This argument must be balanced against the argument that oil import vulnerability represents an externality with potentially dire consequences; therefore, Korea is better off to sacrifice some degree of economic efficiency (and the economic growth that goes with it) to reduce its vulnerability. For an economy such as that of the United States, which has a large domestic resource base, it would be difficult to argue that large sacrifices in economic efficiency should be made. For a pipeline economy such as Korea, however, the answer is not so clear. Further analysis of this issue by Korean policymakers would be worthwhile.

The current integrated energy model continues to be used in Korea to help formulate and analyze balanced, multisector energy policies. Aside from providing the ability to examine the effect of various policies in a consistent and integrated fashion, much of the value of the current integrated model lies in the ease with which its structure can be updated to reflect new information or new policy directions. Such flexible integrated modeling approaches are receiving increased attention from a number of developing and industrialized countries in developing integrated national energy planning.

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