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North Korean Energy Sector: Current Status and Scenarios for 2000 and 2005

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Introduction and Background

The actions, postures, and circumstances of the Democratic People's Republic of Korea (the DPRK or North Korea) have been the focus of significant world attention over the past four years. The much-publicized problems regarding the DPRK include concerns about nuclear proliferation, economic decline, ever-present security issues, energy shortages, floods, and, most recently, food shortages. All of these problems have their roots in both recent and more distant Korean and world history—roots that are both deep and tangled. Various bilateral and multilateral approaches have been fashioned or proposed over the last few years to attempt to address the problems of the DPRK. The Korean Peninsula Energy Development Organization (KEDO), for example, was created to address the politically linked problems of nuclear proliferation, electricity-sector development, and, more broadly, engagement of the DPRK in cooperative projects of concern to the nations of Northeast Asia.

The goal of this chapter is to provide a brief overview of the recent and current status of the North Korean energy sector, as well as examine some of the factors that will influence the development (or continued decline) of the sector over the next eight years and beyond. The energy sector in the North has been a particular focus of the authors' research and analytical work over the past several years (Von Hippel

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and Hayes 1995; Von Hippel and Hayes 1996; Hayes and Von Hippel 1997b).

The North Korean Social and Political System and Its Influence on the Energy Sector

The *juche* or autarchic philosophy of the North Korean government has shaped the electricity and energy sectors in the DPRK. Development of indigenous resources—notably coal—has taken precedence, as has "reverse engineering"[1] and other techniques of developing technologies that can be produced domestically. The focus on domestically produced energy technologies, and the corresponding lack of technology imports (especially recently), has resulted in an energy sector that is notably inefficient. Another major factor in shaping the North's electricity and energy-consuming infrastructure has been the influence of Russian advisors and aid. The former Soviet Union was intimately involved in designing and, in many cases, providing equipment for, constructing, and even operating thermal power plants, industrial plants, and many other elements of the North Korean economy. As a consequence, Russian design criteria and operating practices are widely used in the DPRK. In many cases, the Russian-designed plants provided to the North operate much less efficiently than comparable processes in other countries, contributing to the overall inefficiency of the economy.[2]

The North Korean workforce is literate, disciplined, and hardworking; these attributes have been key in enabling the DPRK to make the economic strides that it did during the phase of heavy industrialization in the two decades following the Korean War. As a result of the DPRK's political isolation, however, the workforce suffers from a lack of technological training. In addition, the relatively low rate of growth of the population means that the workforce is aging. This trend may cause average workforce productivity to decline over the long term (all else being equal, as the ratio of active workers to retirees declines), and it may present problems in retraining workers for new, higher-technology jobs (for example, to make goods that would be competitive in the export market). Academics and engineers involved in the basic sciences and in applied research and development probably also suffer lower productivity due to limited and tightly controlled contact with their peers in other countries.

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1. In "reverse engineering," a device or technology is acquired from outside the country, disassembled, and evaluated to figure out how it works and how it was made. A domestic process for production of the item is then designed.

2. In some cases, reportedly, the infrastructure exported to the DPRK from the former Soviet Union was built to extrarugged specifications for longevity under DPRK conditions. Often, this involved a tradeoff that resulted in reduced energy efficiency.

The North Korean government has shown a preference for massive construction projects. This predilection, plus the ability to muster large workforces rapidly, is helpful when constructing hydroelectric impoundments, barrages (seawalls), and other large public works such as those erected in recovering from the floods, but it is less helpful in constructing smaller, more specialized, and more efficient equipment. The large outlays by the government (reportedly $890 million per year; *Nikkei Shimbun*, 19 May 1997, 8) for massive monuments honoring the Kim regime have siphoned off money and labor that could have been used for energy-sector projects or other (arguably more useful) social infrastructure projects.

Another workforce issue is that a significant fraction (probably on the order of 17 percent) of the males with the potential to be economically active are in the armed forces of the DPRK. Although soldiers apparently participate in public works projects and in some other civilian economic activities (such as harvesting of crops), the proportion of workers in the active armed forces (and the time spent by the 5 million reservists in military training) undoubtedly acts as a drain on the overall economy,[3] including its energy economy.

The "Agreed Framework" and KEDO

As a condition of the October 1994 Agreed Framework signed by the governments of the United States and the DPRK, the DPRK is to be supplied two pressurized-water-type light-water nuclear reactors (referred to as PWRs) for electricity generation in exchange for abandoning its existing graphite-moderated nuclear research reactors and taking further steps to comply with nuclear safeguards. Until the reactors are completed, the Korean Peninsula Energy Development Organization has an obligation under the Framework to supply 500,000 metric tonnes (te) of heavy fuel oil (HFO) to the DPRK annually. KEDO oil deliveries started in 1995, and deliveries in the year ending October 31, 1996, were scheduled to total 500,000 tonnes (KEDO 1996). The oil delivered by KEDO is intended to be used to fuel electricity generation facilities and, nominally, is intended to help the DPRK maintain electricity supplies while the PWRs are under construction.

This proposed transfer of PWR technology is sought by the DPRK as a means to maintaining both a civilian nuclear program and the threat of a military nuclear program. At the same time, it is attractive to other nations (led by the United States) as a means to start the thawing of relations with the DPRK, to lessen the probability of nuclear weapons

3. This drain is in addition to the direct financial outlays for maintenance of the armed forces.

proliferation, and to exert better international control over the North Korean nuclear program. Funding for the PWR transfer is likely to come from the recently formed KEDO, which obtains its financing mostly from the Republic of Korea (ROK or South Korea), with some additional inputs from the United States and Japan.[4] Although energy efficiency and renewable energy measures could conceivably provide the same energy services to the North Korean economy as would the PWR, and could do so on at least a similar time scale and for lower cost (Von Hippel and Hayes 1995; Von Hippel and Hayes 1996; Hayes and Von Hippel 1997b), energy efficiency measures are not politically substitutable for the PWR transfer. The PWR transfer—or some similar arrangement—is a necessary first step to a political opening by the DPRK, an opening that could lead to investments—such as investments in energy efficiency—that will serve to start to integrate the economy of the DPRK with the other economies of the region. This integration, which would enhance stability and security in the region in the medium and long term, is the underlying logic implicit in the hopes of US and South Korean policymakers to achieve a "soft landing" for the North Korean economy and polity.

Although the oil transfers and PWR construction carried out under the Agreed Framework are not likely to have major *direct* impacts on the quality of life in the DPRK, the framework contains major confidence-building measures, and—if adhered to by all parties—should have important *indirect* positive impacts on the North Korean economy. In particular, if cooperation on HFO transfers and PWR issues between the DPRK, the ROK, the United States, and other parties proceeds smoothly, it should open the door to further external collaborations on topics like transfer of advanced (and less-polluting) energy and industrial technologies, cooperation on regional environmental issues, and general development (or redevelopment) assistance to the DPRK.

Plan of This Chapter

The remainder of this chapter is organized as follows:

- we outline "The Recent and Current Status of the North Korean Energy Sector" in the next section, focusing on the status of supplies of and demand for electricity;
- in "Recent and Current Energy-Sector Problems in the DPRK," we describe some of the current problems in the electricity sector, in-

4. Though funding for KEDO has come from the countries indicated, the DPRK will be obliged to repay the funds loaned to build the PWRs. As of late June 1997, KEDO and the DPRK were to sign an agreement specifying penalties if the DPRK fails to repay the loan (*Chosun Ilbo*, 20 June 1997).

cluding the implications of those problems for the measures undertaken as part of the Agreed Framework;

- in "Two Scenarios of North Korean Energy-Sector Development," we present the major assumptions and results of two scenarios for the future of the energy sector in the North; and
- in "Implications of Results and Strategies for Cooperation," we supply our summary as to the current and future efficacy of measures undertaken under the Agreed Framework, as well as provide suggestions regarding cooperative ventures to help address energy-sector and related issues in the DPRK.

The Recent and Current Status of the North Korean Energy Sector

The status of the North Korean energy sector in general, and the electricity sector in particular, provides the underlying motivation—at least the stated motivation—for the North's interest in nuclear power. In this section, we provide a thumbnail portrait of the energy sector, focusing on electricity supply and demand, as it was in 1990 and as it reportedly is today.

Overall energy use per capita in the DPRK is relatively high, primarily because of inefficient use of fuels and reliance on coal. Coal is more difficult to use with high efficiency than oil products or gas. Based on our estimates, primary commercial energy[5] use in 1990 was approximately 67 GJ per capita, approximately 3 times the per capita commercial energy use in China in 1990, and about 50 percent of the 1990 per capita energy consumption in Japan (where 1990 GDP per capita was some 10 to 20 times higher than the DPRK).

The industrial sector is the largest consumer of all commercial fuels—particularly coal—in the DPRK. The transport sector consumes a substantial fraction of the oil products used in the country. Most transport energy use is for freight; the use of personal transport in the DPRK is very limited. The residential sector is a large user of coal and (in rural areas) biomass fuels. The military sector, by our estimates, consumes an important share of the refined oil products used in the country. The public/commercial and services sectors in the DPRK consume a much smaller share of the fuel supplies than they do in industrialized countries, primarily because of the minimal development of the commercial

5. *Primary energy* counts all fuel use, including conversion and transmission/distribution losses. *Commercial energy* excludes, for the most part, use of biomass fuels such as firewood and crop wastes.

sector in the DPRK. Wood and crop wastes are used as fuels in the agricultural sector, and probably in some industrial subsectors as well.

The annex to this chapter provides our estimated Summary Energy Balances for the DPRK for 1990 and 1996, as well as the provisional results of our two scenarios for the years 2000 and 2005.

Energy Resources in the DPRK

The key fuel/energy resources for generation of electric power in the DPRK are fuels for thermal power plants—principally coal—and hydraulic resources to power hydroelectric plants. Resources for nuclear and renewable generation are also available, but their use is currently very limited.

Fuels for Thermal Power Generation

The DPRK's major energy resource is coal. The DPRK has substantial reserves of both anthracite and brown coal, though the quality of its coal reserves varies substantially from area to area. Overall reserves of coal in the DPRK have been estimated (variously) at 600 million tonnes "recoverable" coal reserves; US DOE EIA 1996), 1.8 billion tonnes (Savada 1993), 7.8 billion tonnes (including both proved and probable reserves; UN 1994), 2.5 to 6.6 billion tonnes of coal equivalent (Moiseyev 1996), and 10 billion tonnes (Trigubenko 1991). These estimates amount to approximately 10 to 100 years of reserves at current consumption. Other sources place reserves at even higher levels—up to 70 to 90 billion tonnes, about one thousand times greater than 1990 annual coal production (document in authors' files [VO1]). There is little, if any, coal cleaning practiced in the DPRK.[6]

There are no operating oil wells in the DPRK. Oil resources reportedly have been located offshore in North Korean waters,[7] although there is substantial uncertainty on this count. All crude oil and some petroleum products were imported (as of 1990) from Russia, China, and Iran, with some additional North Korean oil purchases reported on the Hong

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6. Coal preparation involves pulverizing and washing coal to reduce impurities such as ash and sulfur. Power plant and industrial boilers, and even the smaller boilers in residential and public/commercial buildings, would be more efficient and easily operated and maintained if they were fueled with prepared coal.

7. North Korean sources tout oil reservoirs amounting to 6 to 10 billion tonnes of crude offshore of the DPRK in both the East and West Sea. Other sources we have contacted on this topic indicate that reserves do exist, but the oil that is there cannot now be economically extracted. Still other, likely more reliable, sources have indicated that little or no oil is present in North Korean offshore areas.

Kong spot market. Since 1990, crude oil imports have been restricted by a number of economic and political factors. Two operating oil refineries produced (as of 1990) the bulk of refined products used in the country. As of 1996, only one of the two refineries was apparently operating, and imports of refined products had not expanded sufficiently to replace the lost production. We have heard no reports of gas used for electricity generation, and the DPRK lacks facilities for gas production or liquefied natural gas (LNG) imports.[8]

There are various types of biomass wastes generated in the DPRK that could conceivably be used (to a limited extent) to generate electricity. These include municipal solid wastes, wastes from crop production and food products preparation, wood products wastes, and wastes from the paper and pulp industries. Some of these wastes may currently be used for industrial cogeneration (of heat and power) or solely to raise steam for industrial processes. We do not know to what extent these wastes may be available for power generation, but we would guess that other demands for the wastes (for example, as feedstocks, as fuels for "biomass trucks," or for rural cooking and heating) would probably consume the bulk of the available supply. Given the condition of North Korean forests (especially in light of the recent floods and food shortages), the use of dedicated wood plantations to fuel electricity generation would not seem to be a short- or medium-term option.

Hydroelectric Resources

The mountainous terrain in the DPRK, and the relatively wet climate, make for hydraulic resources suitable for hydroelectric development. Hydroelectric resources in the DPRK were developed extensively during the Japanese colonial period, when the northern part of the Korean peninsula supplied much of the peninsula's power, primarily from hydroelectric sources. At present, a total of roughly 4,500 MW of hydroelectric capacity is installed, and estimates of total hydroelectric potential in the DPRK range from about 10,000 (Trigubenko 1991) to 14,000 electric MW (Moiseyev 1996; document in authors' files [EE1]).

Nuclear Options

The DPRK, like the ROK (UN 1994), possesses "considerable" resources of uranium (document in authors' files [EE1]). Starting in the mid-1960s, and with technology and technological assistance from the Soviet Union, the DPRK built a research reactor (initially 2 kWt, later upgraded to

8. There may be use of refinery, coke oven, or blast-furnace gases for cogeneration of heat and electricity in industrial settings, but we have no direct evidence of it.

8 kWt) at Yongbyon. In the 1980s, the DPRK constructed its 30 MW gas-cooled reactor,[9] which is graphite-moderated and capable of using natural uranium (Savada 1993). In this way, the DPRK was able to avoid relying on foreign suppliers for uranium enrichment technologies. The DPRK constructed a reprocessing facility at Yongbyon, apparently to produce weapons-grade plutonium out of the spent fuel from the gas-cooled reactor. It has agreed to shut down and dismantle its nuclear facilities as part of the provisions of the Agreed Framework.

In order to use its uranium resources in the PWRs to be supplied by KEDO as part of the Agreed Framework, the DPRK either will have to construct enrichment facilities or, more likely, will reach an agreement with a supplier who will process and enrich natural uranium mined in the DPRK and thereby provide finished reactor fuel.

Other Renewable Generating Options

Apart from hydroelectric resources, the DPRK's potential renewable resources for electricity generation include tidal, wind, and solar power. The tidal power potential of the DPRK has been estimated at 4,700 MW (Trigubenko 1991). The Nampo lock gate project (also sometimes referred to as the West Sea Barrage) reportedly was to have had a tidal power component, but apparently the power generation aspect of the project was discontinued because of "expected" high capital costs (document in authors' files [EE1]). We do not know at what stage the project was canceled, or what the generation capacity was to have been.

Various sources, and the prevailing topography and wind patterns on the Korean peninsula, suggest that there may be a substantial wind resource in the DPRK. There have been reports of experiments with small wind turbines, but we do not know where or how large the wind machines installed (if any) were. Official publications have expressed interest in developing wind power, particularly in isolated areas such as offshore islands.[10] The areas bordering China are mentioned as having a particularly good wind resource. As a temperate country with both cloudy and sunny weather periods, and flat land at a premium, DPRK's suitability for either solar thermal-electric or solar photovoltaic power is probably only fair to just average.[11]

9. The output of this plant is given as 25 MW, 30 MW, and 5 MW (the latter as electric capacity) by different sources.

10. This seems to indicate that North Korea's energy decision makers and researchers do not tend to think of wind power as a resource suitable for connection to the grid. Why this would be is unclear.

11. In terms of surface insolation (sunlight reaching the surface), the Korean peninsula receives a score of 150 to 175 (units unspecified) on a map where global insolation varies between 75 to 100 (high latitude and polar regions) and 250 to 275 (arid and desert regions). See Sellers 1965.

North Korean Electricity Generating Facilities

There are reportedly over 500 electricity generation facilities in the DPRK. Of these, however, only 62 major power plants reportedly operated as part of the interconnected transmission and distribution grid as of 1990, with the remaining plants being primarily small, isolated hydroelectric facilities and/or facilities associated with industrial installations. These 62 plants include 42 hydroelectric plants and 20 thermal plants. Eighteen of the thermal plants are fired primarily with coal (document in authors' files [EE1]).[12] The power generation system in general suffers from a lack of spare parts in many instances, as well as the absence of testing equipment for use in maintenance activities.

Although there are discrepancies among the various estimates of the installed capacity of thermal electricity generating capacity in the DPRK,[13] we have assumed that the total installed thermal generating capacity as of 1990 was approximately 3,400 megawatts. Of the major thermal power plants that are connected to the national transmission and distribution (T&D) grid, only two are reported to be oil-fired. Of these, by far the largest is the 200 MW plant at Sonbong (referred to in various transliterations as "Oungi," "Oung gi," and "Unggi") where many of the KEDO heavy fuel oil (HFO) deliveries have been made.[14] Since 1990, the only reported major addition to the roster of thermal power plants has been the completion in the early 1990s, with Russian assistance, of one 50 MW unit at the (reportedly) 150 MW East Pyongyang plant.

As noted above, the DPRK has a fairly extensive total potential for hydroelectric development. The North's ability to mobilize massive workforces for public works projects such as dams has helped the country to tap this potential, and as of 1990 approximately 4,500 of an estimated 10,000 to 14,000 MW of hydroelectric potential had been developed. Twenty major hydroelectric plants account for approximately 90 percent of the 4,500 MW of hydroelectric capacity reportedly in service as of 1990. Electricity from several plants (including the output of turbines totaling roughly 700 MW of capacity) is exported to China.

Much of the DPRK's generation capacity was installed in the 1970s and 1980s, with extensive Soviet aid, although a significant portion of

12. One estimate suggests that 85 percent of total national generation takes place in the 62 major power plants. Another reliable source has told us that virtually all generation in the DPRK takes place at about 30 major generating stations, and that all of the other plants, to the extent that they actually exist, are very small, inoperable, or both.

13. Choi (1993), for example, cites a total capacity for coal-fired generating stations of 2,850 MW in 1991, while the United Nations lists 4,500 MW of thermal capacity for 1989 though 1992. Other documents in our files list a total of 2,900 MW of capacity as of 1990 in the largest seven thermal plants alone, and still others list "official figures" of up to 6,000 MW of thermal capacity in 1990.

14. If, indeed, a second oil-fired plant exists, it must be quite small.

generation facilities—particularly hydroelectric facilities—date back to the Japanese occupation.[15]

As of the early 1990s, nearly 3,000 MW of hydroelectric facilities were reportedly under construction in the DPRK. We have little or no information about how construction on these projects (if any) has progressed, or what effect the floods of 1995 and 1996 might have had on ongoing hydro projects. The only exception is the Kumgang Mountain plant, a first phase of which (about 125 MW) was opened in 1996. This modest addition, however, is overwhelmed by the reported loss in hydroelectric capacity caused by the impacts of the 1995 and 1996 floods (see the section "Damage to Hydroelectric Plants," below).

Estimated Electricity Generation and Demand in the DPRK

By our best estimate, a total of 46 TWh (terawatt-hours) of electricity was generated in the DPRK in 1990. This estimate is roughly midway between the state's official estimates (of 60 TWh and greater) and estimates by South Korean sources (27.7 TWh; Korea, Republic of, Ministry of Information 1996), published Russian sources (35 TWh; Moiseyev 1996), and more informal estimates of 31 to 32 TWh (A. Karabanov, personal communication, 1993), but the latter may be a consumption rather than a production figure. The estimated per capita electricity demand in the DPRK in 1990 (subtracting electricity losses, exports to China, and use within power plants) was somewhat over 1,400 kWh per capita. By way of comparison, overall 1990 electricity demand in ROK was about 2,200 kWh per capita (KEEI 1991). Based on our estimates, electricity generation in the DPRK had fallen to less than 24 TWh (625 kWh per capita demand) by 1996.

Electricity generation as of 1990 was primarily hydroelectric and coal-fired, in approximately equal proportions, with a small amount of oil-fired electricity generation taking place at the 200 MW plant associated with the oil refinery at Sonbong. By 1996, as a result of damage to hydroelectric facilities, a much greater proportion of electricity was generated at thermal plants. Estimated North Korean electricity generation by plant type in 1990 and 1996 is shown in figure 1.

As with coal, the bulk of the electricity demand in the DPRK is in the industrial sector, with the residential and military sectors (by our estimates) also accounting for significant fractions of electricity consumption. The patterns of electricity demand by sector in 1990 and 1996 are shown in figure 2.

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15. Most of the thermal power plants in the DPRK (and a large portion of the country's industrial capacity as well) were built with substantial technical and financial assistance from the Soviet Union. The USSR also assisted the DPRK in rebuilding most of the major hydroelectric facilities.

Figure 1 Estimated electricity generation by plant type, 1990 and 1996

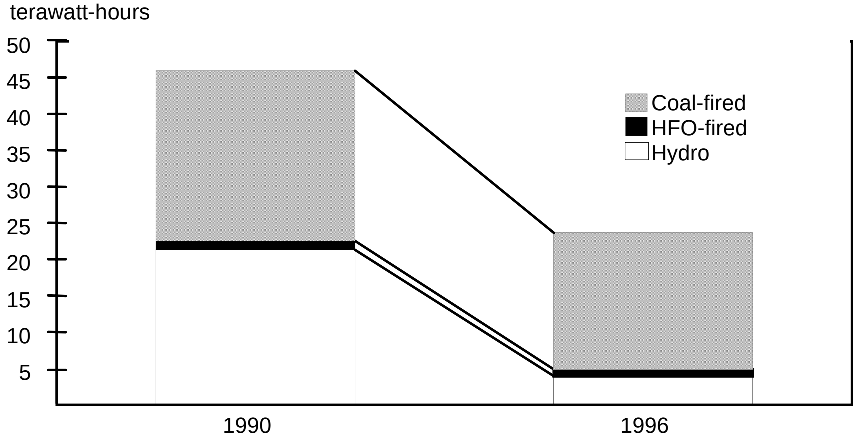
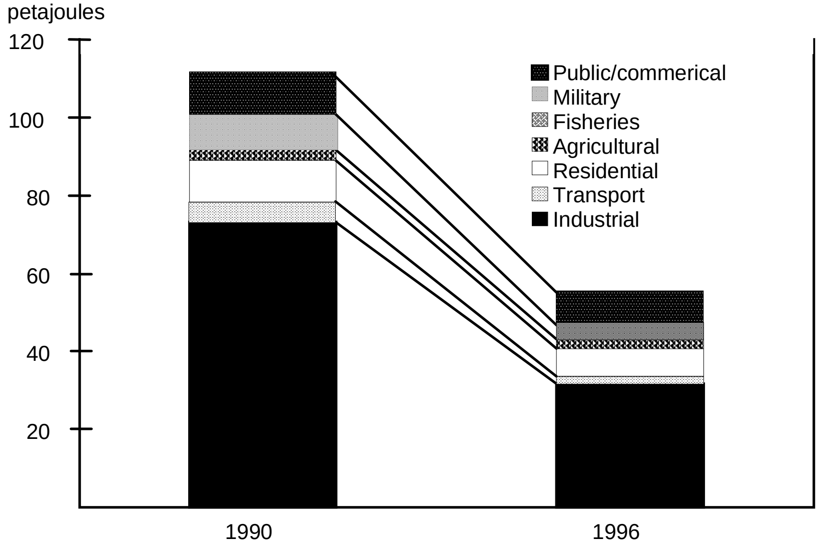


Figure 2 Estimated electricity consumption by sector, 1990 and 1996



Note: Fisheries consumption of electricity is too small to be seen on this graph.

The Disposition of HFO Supplied by KEDO in 1996

The heavy fuel oil supplied to the DPRK by KEDO was and is intended for use as a fuel for electricity generation. HFO supplied by KEDO during late 1995 and 1996 has been burned at the oil-fired power plant at Sonbong, and it has been used to improve the quality of coal used at several other thermal power plants.[16] As the capacity of the DPRK to absorb both heavy fuel oil and electricity has been limited by the poor state of the economy, a substantial amount of HFO has had to be placed in storage. Of the approximately 1,060,000 tonnes of HFO that constituted the DPRK's supply in 1996 (about 500,000 tonnes of which were supplied by KEDO), we estimate that 27 percent was used by industry, 27 percent was used in the oil-fired plant at Sonbong, 31 percent was used in (nominally) coal-fired power plants, and the remaining 15 percent (over 150,000 tonnes, or nearly a third of KEDO supplies) was placed in storage. Broadening the ways in which KEDO HFO can be used under the terms of the Agreed Framework to include key industrial activities—especially production of the mineral magnesite, for which oil-fired equipment apparently already exists in the DPRK—would help to relieve pressure on the North's oil storage facilities.

Recent and Current Energy-Sector Problems in the DPRK

Problems with Fuel Supply

There have been many reports of problems with fuel supply in the North the last several years. Although it is often difficult for outsiders (and probably for most residents as well) to discern the ultimate cause and extent of these problems, fuel supply difficulties certainly include

- *a lack of oil products*, particularly motor fuels, caused by a lack of foreign currency (or will) to pay for imports of crude oil and refined products, and the withdrawal of Russian oil supplies formerly available on a "soft money" basis;
- *maintenance* (and possibly fuel supply) problems on railroad lines and equipment that cause bottlenecks in coal shipments;

16. This use of HFO has been in excess of the fraction of oil fuel usually used as a "starter" fuel in coal-fired power plants. Nominally, this added oil fuel would constitute an uneconomic use of HFO, as coal is available as a less-expensive fuel. However, because the quality of coal available in the DPRK has been deteriorating, HFO has likely become more important as an additive to raise the heating value of power plant fuels.

- *equipment and flooding problems in coal mines*, including lack of investment in new infrastructure or spare parts; and
- *problems with electricity plants and with the electricity transmission and distribution system* (as described below).

Lack of fuels in many sectors of the North Korean economy has apparently caused demand for energy services to go unmet. Electricity outages are one obvious source of unmet demand, but there are also reports, for example, that portions of the North Korean fishing fleet have been idled for lack of diesel fuel. Residential heating is reportedly restricted in the winter to conserve fuel, resulting in uncomfortably cool inside temperatures. The problem posed by suppressed and latent demand for energy services is that when and if supply constraints are removed, there is likely to be a surge in energy use (probably particularly electricity), as residents, industries, and other consumers of fuels increase their use of energy services toward desired levels.

Damage to Hydroelectric Plants

We have recently learned that a significant portion—perhaps as high as 85 percent—of the DPRK's hydroelectric generating capacity has been rendered unusable by the floods of 1995 and 1996. This seems believable, as major hydroelectric facilities are located in the areas where some of the worst flooding occurred, and according to anecdotal reports large amounts of silt and other debris were washed downriver by the floods. Other reports have indicated that relatively little damage to hydro facilities had occurred as a result of flooding,[17] but because major hydro facilities are remote and the damage is not immediately visible, many visitors might find such problems hard to detect. We assume that most of the damage done by the floods has been to fill impoundments with silt, reducing the capacity of dams and clogging spillways and channels. It is possible that damage to gates, turbines, and other mechanical equipment has also occurred.[18] Of these problems, the siltation of reservoirs may be the most difficult for the North Koreans to reverse, as it requires both heavy equipment (and fuel) that the DPRK does not have to spare and considerable time to accomplish.

17. Several sources who have been to the DPRK recently said they had no knowledge of major damage to large hydroelectric facilities. Another source had heard of damage to "one or two" "small to medium-sized" (less than 10 MW) plants.

18. At one point during the 1996 floods, the water levels in one chain of hydro facilities along a river in the north of the country were reportedly such that the turbines actually spun *backward*. One would expect this type of circumstance to cause at least some equipment damage.

Equipment Problems at Thermal Power Plants and Load Centers

Power generation facilities are reported to be in generally poor condition —and often (because they are based on technologies adopted from the former Soviet Union, China, or elsewhere) not well adapted to the coal types with which they are fired. The downturn in the North Korean economy of 1989 through the present, coupled with a sharp reduction in the amount of concessional aid available from Russia, has left the DPRK unable to afford key spare parts (including boiler tubes for thermal power plants). As a consequence, the generation efficiency of the thermal power stations in the DPRK is reportedly low, and breakdowns are frequent. Thermal power plants generally lack all but the most rudimentary pollution control equipment, and also, in almost all cases, lack any kind of computerized combustion control facilities. In-station use of power is reportedly fairly high, and "emergency losses" of power have been reported at major stations.

Much of the energy-using infrastructure in the DPRK is reportedly antiquated and/or poorly maintained. Buildings apparently lack insulation, and the heat in residential and other buildings apparently cannot be controlled by residents. Industrial facilities are likewise either aging or based on outdated technology, and often (particularly in recent years) they are operated at less-than-optimal capacities, from the point of view of energy efficiency.

The Status of the North Korean Transmission and Distribution Grid

The unified electrical grid in the DPRK apparently dates back to 1958 (Moiseyev 1996). The T&D system must manage a fairly complex grid of 62 power plants, 58 substations, and 11 regional transmission and dispatching centers. The T&D system is supposed to be controlled by the Electric Power Production and Dispatching and Control Centre (EPPDCC) in Pyongyang.

The system of electricity dispatching is inefficient, automated minimally or not at all, and prone to failure. Estimates of T&D losses vary from an official 16 percent up to more than 50 percent, but any such estimates are difficult to confirm, as there is minimal end-use metering in the DPRK.[19] Connections between the elements of the T&D system were, as of the early 1990s, reportedly made wholly by telephone and telex, without the aid of automation or computer systems. This system results in poor frequency control, poor power factors, and power out-

19. That is, in general power is simply provided to consumers without metering, so "sales records," as such, do not exist.

ages.[20] Outages on the grid are said to be frequent, and the process of reacting to outages and isolating areas where the outages occur is cumbersome and slow, often resulting in a cascading series of outages (and further delays in restoring power). Poor frequency control and low power factors can damage end-use equipment and can shorten the life of T&D components (Hayes 1997). In addition, outages result in significant economic losses as a result of lost industrial production and services. As of 1990, the EPPDCC lacked direct access to even the most rudimentary data from power plants and substations, having direct readouts of neither *measurements,* such as voltage, current, active power, and frequency, nor *status indicators,* such as open/close conditions of circuit breakers or switch positions. The only exception to this lack of access as of 1990 were links to three power plants, but even these links were reportedly "slow and outdated."

When a transmission fault or power plant failure disrupts the system, or when voltages or frequencies at load centers fall below permissible levels, the EPPDCC staff must rely on telephone and telex to guide remote operators in restoring the system, without access to complete system information on which to base their instructions.

The T&D system also reportedly suffers from poorly maintained transmission lines and substations. In addition to the lack of proper equipment noted above, equipment problems include inadequate or missing insulators on power poles, lack of insulation on power lines, and inadequate wire tension.[21]

Institutional Problems

A thorough description of the institutional problems that must be grappled with during any attempt to improve the DPRK's energy situation is beyond the scope of this chapter. Two major categories of problems are

- The *fragmentation of institutional responsibility*: In the energy sector, this inhibits efforts to upgrade the DPRK's energy systems in general, and the electricity generation and T&D systems in particular. More than a dozen agencies are involved in the electricity sector, but there is no single institution in the DPRK that is fully responsible for elec-

20. A nearly completed UNDP-funded project, "Electric Power Management System," was designed only to address control systems at four critical power plants and four substations around Pyongyang.

21. Some of these problems are apparently institutional: those work units charged with maintaining power lines are different from those responsible for generating power, and they are not supplied by central authorities in the DPRK with the funds or equipment to provide proper T&D maintenance.

tricity systems operations, energy analysis related to electricity production and consumption, integrated planning, and management.

- The *lack of energy product markets*: Confounding attempts to improve efficiencies of energy supply and consumption in the DPRK, and compounding the risk of a surge in the use of energy services if supply constraints are removed, is the virtual lack of energy product markets. Without fuel pricing reforms, there will be few incentives for households and other energy users to adopt energy efficiency measures or otherwise control their consumption of fuels. Energy consumers are also unlikely, without a massive and well-coordinated program of education about energy use and energy efficiency, to have the technical know-how to choose and make good use of energy efficiency technologies.

The KEDO-Supplied PWRs in the North Korean Grid

The power grid in the DPRK operates at a nominal frequency of 60 Hz (Hertz, or cycles per second). Frequency control is poor, however, and the actual frequency on the system often reportedly falls to 57 to 59 Hz, and sometimes as low as 54 to 55 Hz.

Of the neighboring countries, both China and Russia have electricity systems that operate at 50 Hz, while the grid in the ROK operates at 60 Hz. This difference means that in order to interconnect the North Korean grid with the Chinese and/or Russian grid, as has been contemplated under the Tumen River Area Development Programme (TRADP), it will either be necessary to convert from 60 Hz to 50 Hz or from 50 Hz to 60 Hz at the intersection of the power grids. Such interconnections are costly: the cost for an interchange to convert 1,000 MW of power has been estimated at $460 million (UNDP 1994). Interchange costs can be offset, however, by reductions in required reserve capacity in one or both of the interconnected systems. That is, the interconnected systems (in aggregate) need not build as many power plants, thus making possible significant capital cost savings.

Although the South Korean power grid operates at nominally the same frequency as the North Korean grid,[22] we suspect that interconnection of the grids, in their present form, will require some power conditioning at the point of interconnection to ensure that the power entering the ROK meets its standards for frequency and other attributes. The best method is probably to add a station near the Demilitarized Zone (DMZ)

22. The fact that the power grids in the Koreas operate at a different frequency than most of the rest of continental Asia (and virtually all of Europe) is probably a legacy of the Japanese occupation. Japan uses both 50- and 60-cycle grids (ZZZAP).

that converts the AC (alternating current) power from the DPRK to DC (direct current) power, then back to AC power synchronized with the South Korean system for export there. This conversion process would be carried out using a series of solid-state devices. Power losses through these types of AC-DC-AC system are minimal, typically much less than 1 percent. The cost of AC-DC-AC systems of the size that would be required is on the order of $125 million per GW of capacity,[23] or on the order of 5 percent of the costs of the PWRs to be transferred by KEDO.

This information about the types and costs of technologies required for power interconversion suggests (to us) two interesting questions related to the priorities of the South's assistance (if forthcoming) in revamping the North's grid:

- Should the first step in assistance be to interconnect the two grids, so that power can be sold (for example) from the KEDO-provided PWRs to the ROK; or would the South (and, ultimately, a unified Korea) be better served by revamping the North Korean system first to make it suitable to synchronize with the South's grid (effectively creating one Korea-wide system), thus avoiding (at least some) power conditioning costs?
- Would it be less expensive and technically less risky (again, assuming that much of the power from the PWRs is to be sold to the ROK) to simply connect the PWRs to the South Korean grid, but *not* (at least initially) to the North Korean grid? Doing so, of course, could create political difficulties quite apart from any practical considerations and might raise additional political questions about the PWR transfer. In this case, it might be necessary to build a new transmission line from the reactor site to the South Korean border.

Apart from any issues of interconnection of the North's grid with Russia, China, or the ROK, the North Korean grid in its current configuration is likely not stable enough to allow safe operation of the PWRs to be supplied by KEDO. First, the size of the grid (at about 8,000 MW) is only marginally large enough to support 2 GW of generation capacity at one site. Crudely, no generating unit should exceed more than about 10 to 20 percent of the total system capability—or the available system

23. Order-of-magnitude cost estimate obtained in conversation with G. Jutte of Siemens Power Transmission and Distribution, Limited (1997). There are many technical issues that will have to be considered when and if AC-DC-AC converters are to be used in Korea, including the line voltage on the North Korean side and the distance over which the power must be transferred. The AC-DC-AC systems could also be used to interconvert 50 Hz and 60 Hz power at the borders of the DPRK with China and Russia; this suggests that the $460 million interconnection cost cited above may be somewhat high (or may include different hardware).

reserve—or the operation of the whole system may be threatened due to unexpected outages (Barber Associates, nd). Since the North Korean grid at present often reportedly operates as a set of isolated (or semi-isolated) grids rather than as a single unified grid, the issue of grid size relative to the size of the PWRs becomes even more important. There are also technical issues associated with the operation of nuclear reactors under conditions in which frequency fluctuations requiring reactor shutdown are common.[24] Second, a nuclear power plant is usually operated as a baseload plant and cannot be quickly powered up and down to follow peak demand cycles. Ascertaining whether a nuclear power plant would be technically appropriate for local demand patterns would require access to data either as yet uncollected or unreleased by the North Korean government. Finally, it remains an open question as to whether a nuclear power plant could be operated safely and its output dispatched, given the parlous nature of the current power operating infrastructure described earlier in this section. Admittedly, it would take five to seven years (if South Koreans were to be the suppliers and architect-engineers) before the PWRs can be completed, which would provide some time to train power system and nuclear plant operators. Nonetheless, the status of the current power system does not inspire confidence that safety and operational objectives would be achieved in the DPRK nuclear power program.

In any case, it is clear that—unless the KEDO-supplied reactors are to be isolated, and their power sold exclusively out of the country—the North Korean grid will have to be substantially refurbished before the PWRs are brought on-line.

Two Scenarios of North Korean Energy-Sector Development

Continuing a thread of research into the present and future of the North Korean energy sector that we have pursued since 1994 (Von Hippel 1996; Von Hippel and Hayes 1996; Hayes and Von Hippel 1997b), the authors are currently preparing a study of two scenarios of energy-sector development in the DPRK through the year 2005 (Von Hippel and Hayes 1997). Some of the key assumptions and results of these scenarios are presented below. The results presented here should be

24. When a reactor must be taken off-line quickly (as when frequency varies too greatly from design parameters), control rods must be rapidly inserted into the reactor core to "quench" the nuclear chain reaction. If a combination of several of these control rods fail to be inserted properly—and the more frequently reactors must be shut down, the more probable this event becomes—the chain reaction can continue, with the possible result being overheating of the reactor core.

considered preliminary, as we are still in the process of revising our analysis.

Description of Scenarios: "Recovery" and "Decline"

Briefly, the general assumptions in the two scenarios are as follows:

- A combination of external aid and internal transition results in a *recovery* of the North Korean economy to levels slightly below those reported for 1990 by the year 2000, surpassing 1990 performance in most sectors by 2005. We have explored variants of the recovery scenario for 2005 that include (a) export of most of the power generated by the KEDO-supplied PWRs to the ROK[25] and (b) the DPRK mostly retaining the electricity from the PWRs for domestic use.
- Internal transitions are not carried out, external aid is not forthcoming in substantial quantities, and the North Korean economy continues, albeit at a reduced rate, its overall *decline* of 1990 to 1996 through the year 2000. After 2000, the economy stabilizes and even recovers slightly (in part as a result of cooperation forced by the PWR transfer) through the year 2005.

Both cases assume that the DPRK and other parties comply with the terms of the Agreed Framework, and that the reactors supplied by KEDO can be constructed and brought on-line by or before 2005—though the latter is arguably a somewhat optimistic assumption.

Specific assumptions in the *recovery* scenario include

- restarting the Sonbong refinery by 2000 and expanding it to 2.5 times its current capacity by 2005,[26] as the oil-fired power plant associated with the refinery undergoes a similar expansion;
- rehabilitation (by 2000) of roughly half of the hydroelectric capacity affected by the floods, with rehabilitation of the remaining capacity by 2005;

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25. Our assumption that the ROK would be the most likely importer of electricity generated by the PWRs is based on the South's status as the supplier of the PWR technology, its rapidly growing need for generating capacity, and recent informal proposals floated by observers from the ROK and the DPRK. If political and technical obstacles can be overcome, however, there is no particular reason why electricity generated by the PWRs could not be exported to China or, when the economy in the Russian Far East improves, to Russia.

26. Russian assistance would be a strong possibility in this endeavor, particularly given that the plant is Russian built and is near the border of the DPRK with the Russian Far East.

- an improvement in generation efficiency at existing coal-fired power plants by 2005 (if power from the PWRs is exported);
- use of HFO in coal-fired plants at a rate of 9.5 percent (2000) and 3.5 percent (2005) of fuel input;
- industrial production (physical output) at 70 percent (2000) and 120 percent (2005) of 1990 values for most subsectors;
- substantial increases in use of passenger transport relative to 1990, and increases in freight transport consistent with increases in industrial output;
- substantial increases in commercial- and public-sector electricity use;
- substantial increases in residential use of electricity; and
- modest increases in military activity—back to 1990 levels by 2000, and above 1990 levels by 2005.

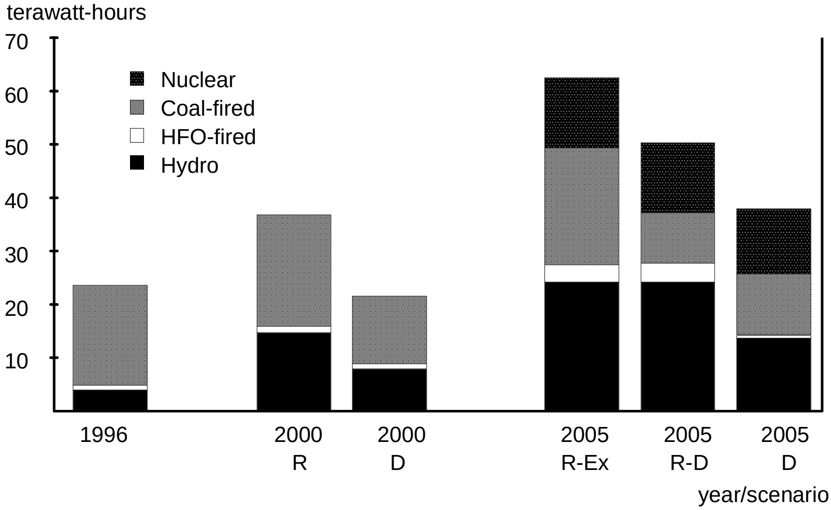
For the *decline* scenario, specific assumptions include

- only limited changes in oil imports relative to the situation in 1996, with the Sonbong refinery remaining off-line;
- repair/rehabilitation of about one-quarter of damaged hydroelectric capacity by 2000, with an additional quarter brought back on-line by 2005;
- use of HFO in coal-fired plants at a rate of 10.6 percent (2000) and 5 percent (2005) of fuel input;
- industrial production at 25 to 30 percent (2000) and 33 to 40 percent (2005) of 1990 levels for most subsectors;
- continued reduction in passenger and freight transport through 2000, with a modest increase in transport use from 2000 to 2005;
- continued slow reductions in residential electricity use through 2000, increasing slightly from 2000 to 2005; and
- continued slow decreases in military activity through 2000, recovering to 1996 levels by 2005.

Scenario Results: Electricity Supply and Demand

An overview of the results of our recovery and decline scenarios with regard to future electricity supply and demand is provided in figures 3 and 4 (respectively). In the recovery scenario, the proportion of electricity provided by hydroelectric plants increases from 17 percent in 1996 to

Figure 3 Electricity supply under different scenarios of energy-sector development

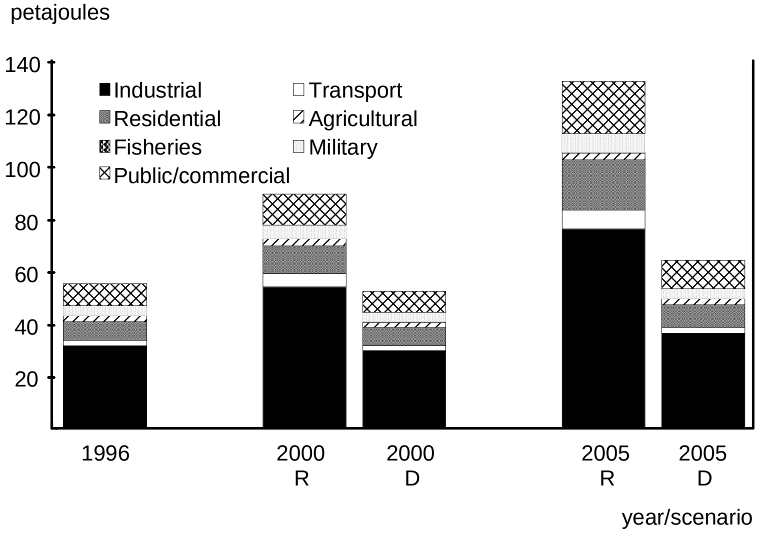


40 percent in 2000. In the variant of the recovery scenario in which power from the KEDO-supplied PWRs is largely exported ("2005 R-Ex" in figure 3), hydroelectric plants provide 38 percent of generation in 2005; in the recovery variant in which PWR generation is retained for domestic use ("2005 R-D" in figure 3), hydroelectric facilities provide just under half of all generation. Overall generation in 2005 is higher in the export variant of the recovery scenario. The use of thermal plants (coal- and oil-fired) drops to 26 percent of total generation in the domestic-use variant of the recovery scenario, as coal-fired generation is displaced by nuclear generation.

In the decline scenario, overall electricity generation falls to just over 23 TWh by 2000, recovering to about 38 TWh in 2005. The latter figure, however, includes 12 TWh of nuclear generation, most of which is assumed to be exported. Hydroelectric production, which is assumed to be impaired due to flood-related damage, makes up only a slightly smaller portion of total electricity generation in the decline scenario than in either of the recovery scenario variants—even though total generation is much lower.

As shown in figure 4, the overall consumption of electricity is markedly different in the recovery and decline scenarios, but the general pattern of electricity demand does not change much. The fraction of electricity demand accounted for by the industrial sector is somewhat higher in the recovery scenarios, but not markedly so. Overall, electricity demand increases at a rate of nearly 13 percent per year through 2000 (and 8 percent per year during 2000 to 2005) in the recovery scenario, while falling at

Figure 4 Electricity demand under two scenarios of energy-sector development



about 1.5 percent per year through 2000 in the decline scenario. After 2000, electricity demand in the decline scenario increases at about 4 percent per year. Though a growth rate in electricity consumption of 13 percent per year seems high for a developing economy, two factors should be considered when assessing the merits of this scenario. First, such growth rates in electricity demand are not unprecedented in Asia, and indeed provide a local case in point. Second, the electricity-using infrastructure in the DPRK exists and is reportedly largely intact.[27] As a consequence, that infrastructure does not, as in a true developing country, need to be built from the ground up.[28]

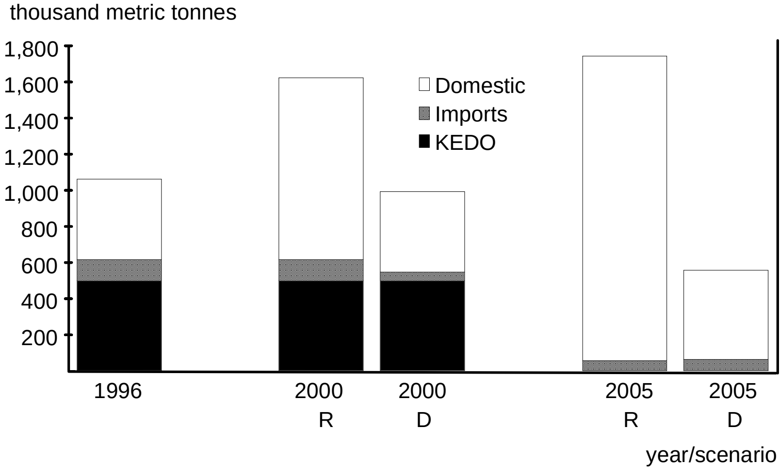
Scenario Results: Disposition of KEDO-Supplied HFO

In the interim period before start-up of the PWRs to be supplied by KEDO, how might the 500,000 annual tonnes of heavy fuel oil shipped

27. Many of the North Korean industrial plants, though recently operating at low capacity factors or completely inactive, have apparently been kept in good enough condition (thanks in part to maintenance procedures established by the Russians) that they can be restarted rapidly given fuel, key spare parts, and demand for goods.

28. However, some new infrastructure will doubtless have to be built when and if the DPRK undergoes the structural adjustments necessary for participation in the regional and global economy.

Figure 5 Supply of heavy fuel oil in the DPRK under two scenarios of energy-sector development

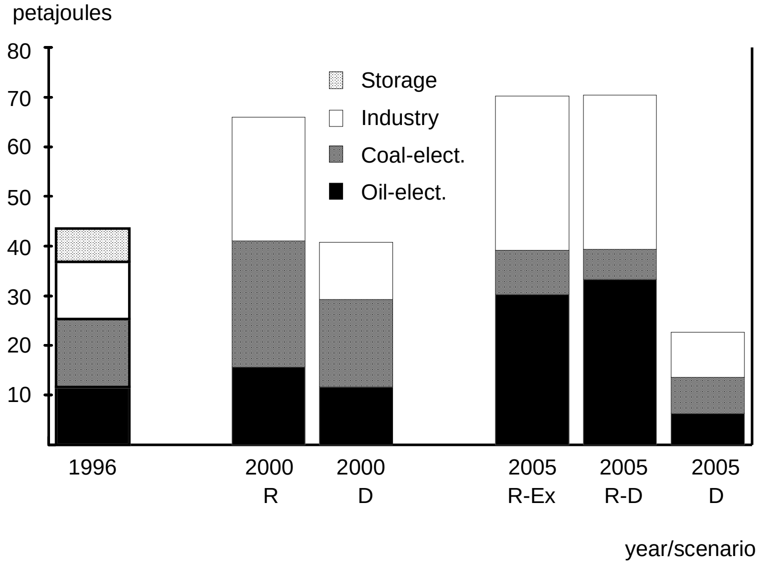


to the DPRK by KEDO be used? Figure 5 shows our scenario results for the contribution of the KEDO-supplied HFO to the total heavy fuel oil supplies in the DPRK, and figure 6 shows the pattern of HFO use under each scenario. The KEDO-supplied HFO constitutes a much larger fraction of total HFO supplies in 1996 and in the decline scenario in 2000 than in the recovery scenario in 2000. In 2005, refinery expansion and crude oil imports may allow the DPRK to maintain and even increase supplies of HFO despite the absence of KEDO deliveries (after the PWRs are built). In the recovery scenarios the expansion of the refinery at Sonbong provides the capacity to more than make up for the cessation of the KEDO deliveries. In the decline scenario, however, 2005 HFO supplies decrease to about half of their 1996 levels as KEDO deliveries cease.

Substantially more HFO is consumed in the industrial sector in the recovery scenarios than in the decline scenario (see figure 6), principally because of increased production of the mineral magnesite for export.[29] More HFO is used for generation at the oil-fired plant at Sonbong in the variant of the recovery scenario in which the PWR power is used domestically than in the variant in which PRW power is exported, and less is used for co-firing with coal. This reduction in HFO in coal-fired

29. We have assumed that some heavy oil is and will be used in industry beyond HFO use for magnesite production, but we do not know in which subsectors the oil is used. This use of HFO in "nonspecified" subsectors totaled about 40 percent of our estimate of total industrial use of heavy fuel oil in 1990.

Figure 6 Demand for heavy fuel oil in the DPRK under different scenarios of energy-sector development



power plants occurs because coal-fired power generation is decreased in the "domestic use" variant of the 2005 recovery scenario.[30]

Estimate of North Korean Production of Plutonium and Other Radioactive Wastes

The DPRK's current inventory of radioactive materials and radioactive waste is not known precisely, but it reportedly includes about 50 tonnes of spent fuel and up to 25 kilograms of plutonium. The amount of radioactive materials and radioactive waste that will be produced when the KEDO-supplied PWRs begin operation will quickly dwarf these existing inventories, and the totals are fairly straightforward to estimate. If we assume that the PWRs operate at a capacity factor of 75 percent in 2005 (as in our recovery scenarios), then the quantities of radioactive wastes generated would be as shown in table 1. Plutonium production will be on the order of 400 kilograms per year, and the total spent fuel to be placed in interim or final storage will be about 40 tonnes. This quantity of spent fuel (after several years' storage in cooling ponds) would re-

30. In fact, the proportion of HFO used in the fuel for coal-fired plants is higher in the "domestic use" variant than in the "export" variant: 5.0 percent versus 3.5 percent, respectively.

Table 1 Projected annual nuclear materials and waste production from KEDO-supplied PWRs, as of 2005 (recovery scenarios)

Reactor capacity (MW)	2000
Annual electricity production (TWh)	13.14
Spent fuel (te heavy metal)	37.4
Plutonium (kg)	374
Strontium-90 (curies)	5,906,102
Cesium 137 (curies)	6,053,440
Low-level wastes (cubic meters)	
High estimate	1,501
Low estimate	878
Low-level wastes (curies)	
High estimate	8,000
Low estimate	2,279
Dry casks needed, spent fuel storage	4

quire approximately four "dry casks,"[31] at a total cost of on the order of $1.5 to $3 million—a relatively small sum compared with the capital cost (estimated at $4.5 billion) of the reactors themselves. Much more likely than dry cask storage—although that remains an option—is reexport of spent fuel to an as yet undetermined location.

Under the terms of the Agreed Framework, the DPRK's current inventory of spent fuel is being placed into storage/transport canisters under international supervision. This process of "canning" the spent fuel, which is proceeding more or less according to schedule, is approximately 80 to 90 percent complete as of this writing (conversation with E. Fei, US Department of Energy, 15 August 1997). The process of placing the fuel in canisters is necessary both to stabilize the fuel for storage and to render it suitable for shipping out of the country for reprocessing. Thus the process is designed to be reversible: the canisters can be opened and fuel can be removed for reprocessing. It is expected that canning will be completed as or before the major components of the PWRs are delivered to the DPRK.

Given the above estimates of the DPRK's plutonium inventory and of nuclear materials production by the KEDO-supplied PWRs, compliance or noncompliance with the terms of the Agreed Framework will produce the following overall outcomes:

31. Data from US DOE (1994). The multipurpose canister (interim storage, transport, and final disposal) described in this document is designed for PWR spent fuel, and the cost of each is given as $354,000. The rough cost range we provide is intended to include ongoing monitoring and evaluation costs.

- If the terms of the Agreed Framework are adhered to, then the existing nuclear facilities in the DPRK will remain frozen, with existing stocks of spent fuel (soon) stabilized and under international supervision. This means that the DPRK will have effectively zero plutonium at its disposal until the KEDO-supplied PWRs are operating. When the PWRs come on line, roughly 400 kg of plutonium will be generated each year, but this larger amount (compared with existing North Korean stocks) of plutonium will be produced under a regional and international political climate that is more cooperative—as a result, in part, of all of the cooperative arrangements necessary for the construction and operation of the PWRs—than it is today. Thus the larger quantity of nuclear material generated is offset by better international supervision and control over the material.
- If the terms of the Agreed Framework are abrogated, production of smaller amounts of plutonium in the DPRK may continue, but in a much less cooperative political environment. Plutonium production in the DPRK in this case may be substantially hidden from international oversight,[32] and diversion of existing stocks of nuclear material becomes more possible.

Implications of Results and Strategies for Cooperation

Summary of Current Situation and of the Impact of KEDO Activities

Electricity production in the DPRK has fallen dramatically since 1990. This decline, however, has more to do with the general weakness of the economy than with specific problems in its electricity sector, although the two are definitely related. A major uncertainty is how fast the hydroelectric plants that were damaged by the floods of 1995 and 1996 can be restored to their preflood capabilities. Assuming that the hydro capacity can be restored, at least in large part, within a few years, we conclude generally that under virtually any scenario, the DPRK will probably have adequate electricity generation capacity to meet its own needs through the year 2005 without adding to its existing stock of generating facilities (including those recently completed or nearing completion). Under scenarios assuming recovery of the North Korean economy, the existing generation and coal-mining capacity will be used at near-1990 levels by 2005. Using the power plants at those levels will almost undoubtedly require substantial rehabilitation or upgrading of many units, as well as of the transmission and distribution system. If recovery continues

32. A discussion of the ramifications of the Agreed Framework is provided in Spector (1996).

past 2005 (and one assumes that it would), more generating capacity or electricity imports will probably be needed shortly after 2005. The timing of this need, however, depends on whether electricity from the KEDO-supplied PWRs is exported or used internally, as well as on the status, by that time, of the thermal and hydro power plants listed as "under construction" as of 1996. Coal supplies should be adequate to fuel generation under any circumstance,[33] the major uncertainty being the status of the coal transport infrastructure. Under a scenario that postulates a continued economic decline, the present generation capacity is much more than adequate.

KEDO heavy fuel oil shipments to the DPRK presently allow the operation of the oil-fired plant at Sonbong. In the absence of the KEDO deliveries, the Sonbong plant would be used considerably less, if at all. The HFO supplied by KEDO is also used in coal-fired plants to help increase the energy content of the fuel. This helps to offset what is reportedly the declining quality of coal used in power plants, and it also helps to boost the efficiency of coal-fired power generation. Because of the damage to hydroelectric facilities, the use of thermal power plants, both coal- and oil-fired, has grown markedly more important over the last two years. Absorption of the KEDO HFO (along with domestically refined supplies) by the North Korean economy will be more difficult under a "decline" scenario, as more of the oil will have to be diverted to coal-fired power plants.

The primary importance of the transfer of the KEDO-supplied PWRs to the DPRK lies in its security and political implications. The major accomplishments of the transfer, if it is successful, will be to have brought the DPRK into cooperative contact with the ROK and the other KEDO partners, to have reduced the potential for nuclear proliferation, and to have started a series of greater engagements between the DPRK and other nations inside and outside the region. The importance of the PWRs to the energy sector in the DPRK is, in our view, a secondary matter, as the same generation capacity (or effective capacity) could very likely be supplied far less expensively if investments in upgrading and refurbishing the energy supply and demand infrastructure in the DPRK, plus investments in selected cost-effective new generation, were pursued instead. Paradoxically, the use of the KEDO-supplied reactors within the North Korean grid will likely require a substantial rehabilitation of the transmission and distribution system, and probably other related energy and transport infrastructure as well. These required spin-off improvements may ultimately prove more useful to the DPRK than the nuclear reactors themselves.

33. However, it is unknown how competitive the overall economics of continued coal production in the DPRK may ultimately be relative to other fuels—such as natural gas—if such fuels become available.

Strategies for Cooperation and Engagement

If the conditions of the Agreed Framework continue to be upheld, KEDO oil deliveries continue to be made, work on the PWRs proceeds as planned, and peace talks between the DPRK, the ROK, and other parties are productive, circumstances should be conducive to engaging the DPRK in cooperative bilateral and multilateral activities on a number of fronts. A few possibilities are offered below.[34]

Cooperation on Technology Transfer for Manufacturing Efficient Electricity-Sector Equipment and Renewable Technologies

Sustained economic recovery in the DPRK will likely require that a large portion of the electricity-sector infrastructure—including electricity supply and demand equipment—be substantially refurbished or completely replaced. Cooperation to assist the DPRK in *manufacturing these types of devices*, for domestic use and potentially for export to other countries, will help toward recovery. Cooperation to establish such manufacturing capability would also ultimately reduce pollution within the countries of Northeast Asia and would reduce transboundary transport of pollution to the rest of the region. Upgrading the electricity-sector infrastructure in the DPRK would help to make their electricity systems more technically suitable for participation in a regional power grid.

Cooperation on production of renewable energy technologies is also an attractive possibility from an economic and environmental perspective. Wind turbine generators are another intriguing possibility, given the apparent success of such ventures in former East-bloc nations (Martinot 1994) and the historical emphasis on machinery manufacture in the DPRK. *Promotion of domestic production of energy-efficient products* is another potential cooperation strategy. This approach could involve ventures such as the establishment of foreign-owned factories for making appliances, lighting products, and other types of energy-efficient equipment, as well as joint ventures between foreign companies and concerns in the DPRK, China, and other countries in which foreign technology is licensed for production in the region. Examples of foreign-owned factories and licensing of technologies abound in the developing world, including a number of ventures in Eastern Europe, the former Soviet Union, and China. It is likely that the earliest examples of such technology transfer to the DPRK will come in the context of ventures in the Rajin-Sonbong Free Economic and Trade Zone.

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34. A more complete discussion of opportunities for regional cooperation is contained in Hayes and Von Hippel 1997a; the authors' other works cited also provide suggestions as to topics for cooperative projects involving the DPRK.

In addition to assistance in manufacturing new energy-sector devices, and perhaps of more immediate concern, the DPRK will likely need help in retrofitting key power plants and T&D infrastructure. The oil-fired generation facility at Sonbong, for example, could likely be converted to combined-cycle operation, with a considerable increase in both capacity and generating efficiency. Retrofitting coal-fired plants for pollution control and fuel substitution (such as natural gas and low-sulfur oil), widening the use of fluidized-bed boilers and potentially integrated gasification combined-cycle coal-fired units, boiler refurbishing, adding boiler process control equipment, and a host of other upgrades to existing infrastructure will be necessary to assist the DPRK in achieving the recovery scenario. Many countries inside (Japan, the ROK, and Russia) and outside (the United States) Northeast Asia have the expertise needed to help with these infrastructural upgrades.

Involving the Private Sector in Investments and Technology Transfer

Much of the money and other assistance necessary to help the DPRK toward recovery and economic development will have to come from the more flexible and faster-moving private sector. It is likely that inducements and guarantees—possibly supplied by other governments of the region—will be necessary in order to mediate the risk to private firms of dealing with the DPRK.

As noted above, one way that the governments of the region, and governments of other countries with an interest in what happens in Northeast Asia (including the United States and Russia), can help in this regard is to *promote joint ventures and licensing agreements*. The governments of the region and other interested parties should promote joint ventures and licensing agreements between North Korean concerns (governmental or otherwise) and foreign firms with energy-efficient production technologies. Compact fluorescent light bulb factories are a commonly cited example demonstrating successful transfer of energy technology (Sathaye et al. 1994). A wide variety of efficient industrial equipment and controls (including adjustable-speed drive motors and improved industrial and utility boilers), efficient household appliances and components, and efficient building technologies already introduced to China through commercial channels are being or will be manufactured there. Local manufacturing can be instrumental in reducing the cost of cleaner technologies, including pollution control equipment, renewable electricity generation equipment, and energy-efficient processes. Funding is needed to adapt imported "clean" technologies so that they can be manufactured locally and so that they are applicable to local conditions.[35]

35. Adaptation of technologies would include, for example, making particular devices suitable for the unit sizes and fuel compositions found in the country where they are to be manufactured and applied.

Cooperation on Nuclear Issues

As the ROK will play a major role in providing equipment for and constructing the nuclear plants in the DPRK, nuclear cooperation between those countries—at least in plant assembly, fuel production, and (probably) operation—is a given. The issue of how to manage the various categories of nuclear waste, however, has not been satisfactorily resolved in the DPRK or, for that matter, in any of the countries of the region. Proposals have been made for an "Asiatom"—a cooperative regional organization designed to coordinate nuclear activities in the countries of the region (and possibly, in the more distant future, to found and manage a regional waste repository).[36] Even short of such a formal regional organization, the ROK and Japan have expertise and technology in techniques for handling of nuclear materials that could be made available to assist the nuclear program of the DPRK.[37]

Cooperation on Environmental Quality

The DPRK at present has neither the financial resources nor the expertise simultaneously to mount a meaningful assault on its environmental problems and to promote a sustained recovery without substantial cooperation from countries inside and outside the region. Of the many environmental concerns currently facing the nations of Northeast Asia, the problem of "acid rain" or "acid precipitation" presents perhaps the most potent combination of immediate and ongoing impact and regional scope. Acid rain, caused primarily by emissions of nitrogen and sulfur oxides (SO_x), is already harming the environment and economies of the countries of Northeast Asia. Acid gas emissions from the DPRK affect both the North and other countries of the region, and the DPRK is also the recipient of acid rain caused by its neighbors.[38]

Helping the DPRK to address acid rain issues, including providing assistance to reduce acid gas emissions and to monitor acid rain and its impacts, may indirectly address some of the underlying energy infrastructure issues in the DPRK in a way that is acceptable to the regime and welcomed by its neighbors. Such assistance could take several forms, including

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36. See, for example, Suzuki (1996) and Choi (1996).

37. In a forthcoming Nautilus Institute Report (Von Hippel and Hayes forthcoming), the authors will present their analysis of spent fuel projections and technical options for interim storage of nuclear materials for the countries of the region.

38. See Hayes and Zarsky (1995), which builds on and summarizes ongoing work on the "RAIN-Asia" project, a joint effort of the International Institute for Applied Systems Analysis (IIASA), Argonne National Laboratory, and many others. See, for example, Streets et al. 1995.

- *Providing the DPRK with fuel oil that has a lower sulfur content*. Use of the relatively high-sulfur HFO supplied by KEDO may or may not result in higher emissions of SO_x than combustion of the fuels that the DPRK would be forced to use in the absence of KEDO supplies,[39] but KEDO's making lower-sulfur HFO available would certainly reduce SO_x emissions by roughly 14,000 tonnes per year so long as the fuel is supplied.[40] This reduction is equivalent to under 2 percent of our estimate of 1990 North Korean SO_x emissions, but is more than 3 percent of 1996 emissions.
- *Helping the DPRK with modifications of boilers and burners to improve efficiency* (and thus reduce all pollutant emissions) *or to add simple "end-of-pipe" emissions reduction equipment* to selected plants.[41] A UNDP project to introduce Chinese fluidized-bed boiler technology to the DPRK is already underway. This project, which could be augmented by assistance from KEDO or others, might provide a vehicle for interesting and engaging China (and reengaging Russia, as a supplier of less-expensive and compatible infrastructure) in North Korean energy issues.
- *Helping to provide training in soil conservation and in environmentally sustainable methods of high-yield agriculture.*

In addition, the DPRK has some acid rain monitoring sites that could be incorporated into regional Northeast Asia monitoring networks. Providing assistance with this integration process would help to build confidence within the DPRK and between the DPRK and its neighboring countries.

Strengthening Regulatory Agencies and Educational/Research Institutions in the DPRK

There is a need to strengthen a variety of the DPRK's government institutions—particularly those whose mandate includes environmental performance—through a combination of providing information, persuading

39. Estimates of the net effect of use of KEDO-supplied oil on SO_x emissions must consider the amount of hydroelectric production that would have been used in the absence of KEDO HFO, the amount and types of domestic coal that would replace the KEDO oil, and the relative efficiencies of combustion of HFO versus domestic coal.

40. We reach this figure by assuming low-sulfur fuel oil (LSFO) of weight 0.6 percent sulfur or less, HFO sulfur content of about 2 percent, and combustion of the full allotment of KEDO-supplied HFO in boilers lacking equipment to control SO_x emissions.

41. See Von Hippel (1996) for a review of the technical alternatives for reducing acid gas emissions.

leaders, training personnel, and supplying institutions with needed equipment. Many of these tasks are being started by UNDP and other ongoing programs.

One general area in which North Korean institutions could be strengthened is in their ability to *implement standards and enforce them*. Government officials have made general statements about their support for energy efficiency and environmental protection. The next step is to codify these generalities in quantitative standards for the efficiency of new appliances and equipment, as well as in stringent effluent standards for new—and perhaps, eventually, existing—factories, power plants, residential heating boilers, vehicles, and other major sources of pollution. Once standards are set, enforcement personnel must be recruited, trained, and supplied with the tools necessary to do their job (testing equipment and adequately equipped labs, for example) and with the high-level administrative support needed for credible implementation of sanctions.

In the DPRK, there is not as yet a single *center of technical excellence* that is devoted to the study and promotion of *energy efficiency and renewable energy* opportunities. We would encourage the formation of such a body, which could be modeled on existing institutions like the Beijing Energy Conservation Center and a similar center in Russia (Chandler, Dadi, and Hamburger 1993; Chandler 1993). It is possible that the Center for the Rational Use of Energy (CRUE), formed within the existing Institute of Thermal Engineering under a UNDP project, could be strengthened through a combination of North Korean and external support into such a center of excellence. The first step will be to start training current CRUE staff in the fundamentals of energy-efficient technologies and analysis.

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Annex: Estimated North Korean Energy Balances for 1990 and 1996, with Scenarios for 2000 and 2005

Table A1 Estimated balance for 1990

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char- coal	Elec.	Total
Energy supply	1,356	111	27	77	382	–	(12)	1,940
Domestic production	1,318	–	–	77	355	–	–	1,750
Imports	68	111	27	–	27	–	–	232
Exports	30	–	–	–	–	–	12	42
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(377)	(111)	89	(77)	(11)	4	111	(371)
Electricity generation	(301)	–	(16)	(77)	–	–	166	(228)
Petroleum refining	–	(111)	104	–	–	–	–	(6)
Coal prod./prep.	–	–	–	–	–	–	(8)	(8)
Charcoal production	–	–	–	–	(11)	4	–	(7)
Own use	(60)	–	–	–	–	–	(12)	(72)
Losses	(15)	–	–	–	–	–	(34)	(49)
Fuels for final cons.	979	–	115	–	371	4	100	1,569
Energy demand	907	–	109	–	376	3	112	1,507
Industrial	572	–	33	–	2	–	73	679
Transport	–	–	39	–	8	–	5	52
Residential	234	–	6	–	262	3	11	517
Agricultural	10	–	5	–	45	–	3	62
Fisheries	–	–	2	–	–	–	0	2
Military	38	–	18	–	–	–	9	66
Public/comml.	35	–	–	–	–	–	11	46
Nonspecified	–	–	5	–	–	–	–	5
Nonenergy	18	–	–	–	59	–	–	77
Elect. Gen. (Gr. TWh)	23.43	–	1.28	21.29	–	–	–	46.00

Table A2 Estimated balance for 1996

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char- coal	Elec.	Total
Energy supply	735	43	33	14	413	–	(1)	1,236
Domestic production	775	–	–	14	386	–	–	1,175
Imports	8	43	39	–	27	–	–	117
Exports	48	–	–	–	–	–	1	49
Stock changes	–	–	7	–	–	–	–	7
Energy transf.	(272)	(43)	15	(14)	(9)	3	56	(264)
Electricity generation	(228)	–	(25)	(14)	–	–	85	(182)
Petroleum refining	–	(43)	43	–	–	–	–	–
Coal prod./prep.	(35)	–	–	–	–	–	(5)	(40)
Charcoal production					(9)	3	–	(6)
Own use	–	–	(2)	–	–	–	(10)	(12)
Losses	(15)	–	–	–	–	–	(34)	(49)
Fuels for final cons.	463	–	48	–	404	3	55	972
Energy demand	463	–	48	–	405	3	55	973
Industrial	213	–	13	–	0	–	32	258
Transport	–	–	15	–	6	–	2	23
Residential	157	–	2	–	323	3	7	492
Agricultural	9	–	2	–	40	–	2	53
Fisheries	–	–	1	–	–	–	0	1
Military	38	–	15	–	–	–	4	57
Public/comml.	35	–	–	–	–	–	9	44
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	11	–	–	–	35	–	–	46
Elect. Gen. (Gr. TWh)	18.78	–	0.96	3.90	–	–	–	23.65

Table A3 Projected balance for 2000: recovery scenario

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char- coal	Elec.	Total
Energy supply	1,092	111	43	53	432	–	(7)	1,723
Domestic production	1,148	–	–	53	400	–	–	1,600
Imports	8	111	43	–	32	–	–	194
Exports	64	–	–	–	–	–	7	71
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(308)	(111)	63	(53)	(12)	4	96	(320)
Electricity generation	(242)	–	(41)	(53)	–	–	132	(204)
Petroleum refining	–	(111)	111	–	–	–	–	0
Coal prod./prep.	(52)	–	–	–	–	–	(7)	(59)
Charcoal production	–	–	–	–	(12)	4	–	(8)
Own use	–	–	(6)	–	–	–	(9)	(15)
Losses	(13)	–	–	–	–	–	(20)	(34)
Fuels for final cons.	784	–	106	–	420	4	89	1,403
Energy demand	783	–	106	–	422	4	89	1,404
Industrial	399	–	28	–	1	–	54	482
Transport	–	–	44	–	8	–	5	56
Residential	276	–	8	–	310	4	11	608
Agricultural	10	–	5	–	45	–	3	62
Fisheries	–	–	2	–	–	–	0	2
Military	39	–	20				5	64
Public/comml.	43	–	–	–	–	–	12	55
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	16	–	–	–	59	–	–	–
Elect. Gen. (Gr. TWh)	20.79	–	1.28	14.67	–	–	–	36.74

Table A4 Projected balance for 2000: decline scenario

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char-coal	Elec.	Total
Energy supply	695	43	32	29	420	–	(4)	1,214
Domestic production	725	–	–	29	393	–	–	1,147
Imports	8	43	32	–	27	–	–	110
Exports	38	–	–	–	–	–	4	42
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(188)	(43)	11	(29)	(9)	3	56	(198)
Electricity generation	(146)	–	(29)	(29)	–	–	78	(126)
Petroleum refining	–	(43)	43	–	–	–	–	–
Coal prod./prep.	(33)	–	–	–	–	–	(4)	(38)
Charcoal production	–	–	–	–	(9)	3	–	(6)
Own use	–	–	(2)	–	–	–	(7)	(9)
Losses	(8)	–	–	–	–	–	(11)	(19)
Fuels for final cons.	507	–	43	–	411	3	52	1,017
Energy demand	508	–	43	–	412	3	52	1,018
Industrial	183	–	12	–	0	–	30	225
Transport	–	–	14	–	6	–	2	21
Residential	234	–	2	–	341	3	7	586
Agricultural	8	–	1	–	36	–	2	47
Fisheries	–	–	1	–	–	–	0	1
Military	38	–	13	–	–	–	4	55
Public/comml.	33	–	–	–	–	–	8	41
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	12	–	–	–	29	–	–	41
Elect. Gen. (Gr. TWh)	12.72	–	0.96	7.92	–	–	–	21.60

Table A5 Projected balance for 2000: recovery scenario, with export of power from KEDO-supplied PWRs

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char- coal	Elec.	Total
Energy supply	1,308	216	(12)	135	450	–	(49)	2,047
Domestic production	1,365	–	–	135	410	–	–	1,910
Imports	8	216	21	–	40	–	–	285
Exports	65	–	33	–	–	–	49	147
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(324)	(216)	165	(135)	(10)	3	182	(335)
Electricity generation	(245)	–	(39)	(135)	–	–	225	(194)
Petroleum refining	–	(216)	216	–	–	–	–	0
Coal prod./prep.	(62)	–	–	–	(10)	3	–	(7)
Charcoal production	–	–	–	–	(12)	4	–	(8)
Own use	–	–	(12)	–	–	–	(11)	(24)
Losses	(16)	–	–	–	–	–	(24)	(40)
Fuels for final cons.	985	–	153	–	440	3	132	1,713
Energy demand	984	–	153	–	442	3	132	1,715
Industrial	563	–	39	–	2	–	76	680
Transport	–	–	63	–	6	–	7	76
Residential	295	–	18	–	331	3	19	667
Agricultural	10	–	7	–	45	–	3	64
Fisheries	–	–	3	–	–	–	0	3
Military	39	–	24	–	–	–	7	70
Public/comml.	55	–	–	–	–	–	20	75
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	22	–	–	–	59	–	–	81
Elect. Gen. (Gr. TWh)	21.90	–	3.20	37.39	–	–	–	62.48

Table A6 Projected balance for 2000: recovery scenario, with domestic use of power from KEDO-supplied PWRs

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char-coal	Elec.	Total
Energy supply	1,169	216	(12)	135	450	–	(12)	1,946
Domestic production	1,226	–	–	135	410	–	–	1,771
Imports	8	216	21	–	40	–	–	285
Exports	65	–	33	–	–	–	12	110
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(185)	(216)	164	(135)	(10)	3	144	(235)
Electricity generation	(115)	–	(39)	(135)	–	–	181	(108)
Petroleum refining	–	(216)	216	–	–	–	–	0
Coal prod./prep.	(56)	–	–	–	–	–	(8)	(63)
Charcoal production	–	–	–	–	(10)	3	–	(7)
Own use	–	–	(12)	–	–	–	(8)	(20)
Losses	(14)	–	–	–	–	–	(22)	(36)
Fuels for final cons.	984	–	153	–	440	3	132	1,712
Energy demand	984	–	153	–	442	3	132	1,715
Industrial	563	–	39	–	2	–	76	680
Transport	–	–	63	–	6	–	7	76
Residential	295	–	18	–	331	3	19	667
Agricultural	10	–	7	–	45	–	3	64
Fisheries	–	–	3	–	–	–	0	3
Military	39	–	24	–	–	–	7	70
Public/comml.	55	–	–	–	–	–	20	75
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	22	–	–	–	59	–	–	81
Elect. Gen. (Gr. TWh)	9.41	–	3.52	37.39	–	–	–	50.31

Table A7 Projected balance for 2005: decline scenario

In Petajoules (PJ)	Coal & coke	Crude oil	Ref. prod.	Hydro/ nucl.	Wood/ biomass	Char-coal	Elec.	Total
Energy supply	735	47	16	94	449	–	(45)	1,295
Domestic production	766	–	–	94	417	–	–	1,276
Imports	8	47	16	–	32	–	–	103
Exports	39	–	–	–	–	–	45	84
Stock changes	–	–	–	–	–	–	–	–
Energy transf.	(184)	(47)	30	(94)	(10)	3	109	(192)
Electricity generation	(140)	–	(14)	(94)	–	–	137	(111)
Petroleum refining	–	(47)	47	–	–	–	–	0
Coal prod./prep.	(35)	–	–	–	–	–	(5)	(40)
Charcoal production	–	–	–	–	(10)	3	–	(7)
Own use	–	–	(3)	–	–	–	(9)	(12)
Losses	(9)	–	–	–	–	–	(14)	(23)
Fuels for final cons.	550	–	47	–	439	3	64	1,103
Energy demand	550	–	47	–	441	3	64	1,106
Industrial	240	–	10	–	1	–	36	287
Transport	–	–	17	–	6	–	2	25
Residential	207	–	3	–	364	3	9	586
Agricultural	9	–	2	–	40	–	2	53
Fisheries	–	–	1	–	–	–	0	1
Military	38	–	15	–	–	–	4	57
Public/comml.	44	–	–	–	–	–	11	55
Nonspecified	–	–	–	–	–	–	–	–
Nonenergy	12	–	–	–	29	–	–	41
Elect. Gen. (Gr. TWh)	11.50	–	0.51	25.98	–	–	–	37.99