THE DPRK ENERGY SECTOR: ESTIMATED YEAR 2000 ENERGY BALANCE AND SUGGESTED APPROACHES TO SECTORAL REDEVELOPMENT

REPORT PREPARED FOR THE KOREA ENERGY ECONOMICS INSTITUTE (KEEI)

Prepared by

David Von Hippel, Timothy Savage, and Peter Hayes

Nautilus Institute for Security and Sustainable Development

125 University Avenue, Berkeley, CA 94710, USA

REVISED DRAFT, March 6, 2003

P. Hayes e-mail: phayes@nautilus.org, D. Von Hippel e-mail dvonhip@igc.org

D. Von Hippel Oregon Address: 910 E 23rd Ave, Eugene, OR 97405 USA

Executive Summary

During the decade of the 1990s, and continuing through these early years of the 21st century, a number of issues have focused international attention on the Democratic People's Republic of Korea (the DPRK). Despite signs of economic improvement, the energy situation in the DPRK remains difficult.

The purpose of this report is to provide policy-makers and other interested parties with an overview of the demand for and supply of electricity in the DPRK in three key years:

- **1990**, they year before much of the DPRK's economic and technical support from the Soviet Union was withdrawn;
- **1996**, thought by some to be one of the most meager years of the difficult economic 1990s in the DPRK; and
- **2000**, a recent year and also a year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK.

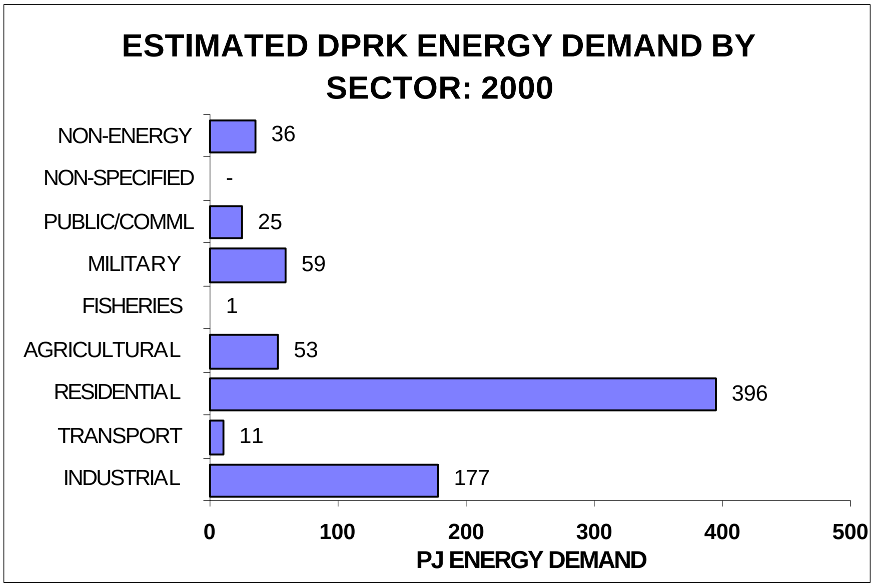
Building on previous energy balances prepared for 1990 and 1996, the authors assembled information from as many data sources as possible to try and update their earlier work to an estimate of year 2000 energy supply and demand in the DPRK. Revised results of the 1990 and 1996 energy balances, and a detailed description of input parameters and assumptions used in the analytical process, are presented in the report that follows.

The estimates of year 2000 energy demand and supply presented here are generally lower than those assembled by others, including international statistical resources and ROK estimates. The estimates described in Chapter 3 of this report include overall year 2000 gross electricity generation of about 12.6 terawatt-hours (TWh, or 12.6 billion kilowatt-hours), coal production of 384 million gigajoules (GJ), or about 13 million tonnes of coal equivalent), crude oil imports of about 600,000 tonnes (or less), and net refined products imports, including oil provided by the Korean Peninsula Energy Development Organization (KEDO) of 40 million GJ, or about 950,000 tonnes. The electricity, coal, and oil imports estimates for 2000 are on the order of one quarter to one third of the levels of output and imports of these fuels as of 1990. The use of wood and biomass has to some extent, particularly in households in rural areas, made up for the lack of commercial fuels.

One major refinery continues to run in the DPRK, but at a much lower level even than in 1996. A minor refinery also apparently operated periodically in 2000. Much of the electricity generation infrastructure in the DPRK is in advanced states of decay, with possibly less than 800 MW of actually operable thermal capacity as of 2000. Hydroelectric plants are apparently in somewhat better condition, but are at the mercy of water availability, and thus operate with relatively low capacity factors. Coal mines are plagued with equipment and transport problems and, most importantly, by lack of electricity to operate mining machinery and lights.

Industrial output is estimated to have declined, by 2000 to 11 to 30 percent of 1990 levels, varying by subsector. As a consequence, the share of overall energy demand contributed by the industrial sector is now second to the residential sector, as shown in figure ES-1, though residential demand includes a substantial amount of wood and other biomass estimated to be used as "substitute" fuels in the absence of coal and electricity.

Figure ES-1:



In Chapter 4 of this report, the authors provide a brief sketch of a "Rebuilding" pathway, for the DPRK economy and energy sector, and describe some of the preconditions and impacts on the energy sector of such a path. Also described in Chapter 4 are a list of institutional changes—ranging from training to establishment of energy pricing practices to strengthening of regulatory agencies to setting out clear and consistent rules for commerce with foreign companies—that the DPRK should adopt and be assisted with in order to work toward rebuilding. Also suggested are a number of areas for international cooperation, including providing technical and institutional assistance in implementing energy efficiency measures, promoting better understanding of the North Korean situation in the ROK, working to open opportunities for independent power companies to work in the DPRK, and cooperation on technology transfer for energy efficiency and renewable energy. Key and attractive energy sector technologies and processes for energy sector redevelopment in the DPRK are identified, including rebuilding of the electricity transmission and distribution system, rehabilitation of power plants and other coal-using infrastructure, rehabilitation of coal supply and coal transport systems, development of alternative sources of small-scale energy and implementation of energy-efficiency measures, rehabilitation of rural infrastructure, advanced investigation of regional electricity grid interconnections, and gas supply and demand infrastructure development.

This document is intended to provide a best estimate, given available data, of an internally consistent year 2000 energy supply/demand balance for the DPRK. It is intended to be revised as more and better data are available, and the authors welcome reader comments and input on the material presented here.

Acknowledgements

The authors would like to acknowledge the support of the Korea Energy Economics Institute in for the preparation of this report, as well as the support of other agencies, including the Alton Jones Foundation and the United States Department of Energy that have funded earlier and related Nautilus research efforts. Thanks also go to the many colleagues who have provided their time and invaluable insights to assist us and guide us in the preparation of this analysis. The authors would also like to thank Ms. Jin Chen for her patient and painstaking assistance in translating tables on China-DPRK trade from Chinese source documents.

Table of Contents

VOLUME OF ATTACHMENTS: WORKPAPERS, BACKGROUND DATA, AND DETAILED RESULTS

1. Introduction and Background: The DPRK Energy Sector

1.1. Purpose and Goal of Report

During the decade of the 1990s, and continuing through these early years of the 21st century, a number of issues have focused international attention on the Democratic People's Republic of Korea (the DPRK). Most of these issues—including nuclear weapons proliferation, military transgressions and posturing, economic collapse, transboundary air pollution, floods, food shortages, droughts, and tidal waves—have their roots in a complex mixture of Korean and Northeast Asian history, global economic power shifts, environmental events, and internal structural dilemmas in the DPRK economy. Energy demand and supply in general—and, arguably, demand for and supply of electricity in particular—have played a key role in many of these high-profile issues involving the DPRK.

The purpose of this report is to provide policy-makers and other interested parties with an overview of the demand for and supply of electricity in the DPRK in three key years:

- **1990**, they year before much of the DPRK's economic and technical support from the Soviet Union was withdrawn;
- **1996**, thought by some to be one of the most meager years of the difficult economic 1990s in the DPRK; and
- **2000**, a recent year and also a year that has been perceived by some observers as a period of modest economic "recovery" in the DPRK.

Requirements for fuels—and the ways in which fuels, including electricity, coal, oil, and biomass, are supplied—are linked to social, political, and economic conditions, and to the demand for industrial commodities. To analyze the status of and prospects for electricity demand, we have developed internally-consistent estimated energy balances for 1990, 1996, and 2000 for the whole of the DPRK economy on a sector-by-sector basis. This method allows a review of the electricity situation in a broader context, and illuminates some of the key issues, options, and uncertainties that must be included in the consideration of electricity supply and demand—present and future—in the DPRK. We conclude with a discussion of what can be done to improve the energy situation in the DPRK, and of the role of international cooperation in assisting the DPRK with addressing energy-sector issues—issues that very often have ramifications beyond its national borders.

This analysis described in this report updates Nautilus studies of the energy situation in the DPRK that have been ongoing since 1995[1]. As a consequence, the estimates presented here

[1] Nautilus experience drawn upon in preparing this study includes analyses of Korean security issues from 1980 on, and more recently: Several consulting missions to the DPRK, on energy sector and environmental issues, undertaken in the early 1990s, for the United Nations Development Programme (UNDP); an analysis of the DPRK's energy situation as of 1990, and an assessment of the degree to which energy efficiency measures could result in improved performance of the DPRK energy sector (Von Hippel, D. F., and P. Hayes, The Prospects For Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options. Nautilus Institute Report, December, 1995); a review of the demand for and supply of heavy fuel oil in the DPRK as of 1996, with demand pathways for the year 2000, prepared for the Korean Peninsula Energy Development Organization (KEDO); research focusing on the DPRK electricity system, updating our estimate of the status of the DPRK energy sector to 1996, and elaborating and evaluating energy pathways for the DPRK to 2005 (D.F. Von Hippel, and P. Hayes, Demand and Supply of Electricity and Other Fuels in the Democratic Peoples' Republic of Korea (DPRK), Nautilus

are in many cases based on earlier work, revised to take into account new information, and the discussions and text provided here are in many cases modified versions of discussions in earlier reports. The goal is to provide, to the extent that time allows, quantitative estimates of three "snapshots" of the evolution of the DPRK energy situation over the past decade. This update endeavors to take into account as much recent and current information as possible, despite the considerable difficulties inherent in obtaining reliable information about the DPRK.

1.2. Summary and History of the Current Economic Situation in the DPRK

The DPRK energy system exists to serve the DPRK economy. As such, we present a very brief review of the recent and not-so-recent history of the economy in North Korea, and of the forces that have helped to shape and change the economy.

1.2.1. Brief history of the evolution of the DPRK economy following WWII, and status as of 1990

Although the affirmation of a unified and independent Korean state was agreed upon by the major powers in discussions during 1943 to 1945, the Yalta Conference at the end of World War II resulted in the partitioning of Korea[1]. The boundary created thereby was altered slightly by the 1953 armistice that suspended hostilities in the Korean War. Since then, the Korean Peninsula has been politically and economically divided. North Korea (DPRK), backed politically by the Soviet Union and the People's Republic of China, was formed in the area south of China and Russia (bordered by the Amnok and Tumen rivers) and roughly north of the 38th parallel, while the portion of the peninsula south of the 38th parallel became the Republic of Korea, backed politically and militarily by a host of Western nations, including the United States. The two Korean states went on to rebuild their shattered economic infrastructure and pursue development in very different ways, aided by their different economic and political partners. The DPRK's economic rise from the ashes of war was impressive, particularly given its political isolation from the Western world. In the last decade, however, the effective end of the Cold War and the substantial withdrawal of economic aid from the former Soviet Bloc, together with other world and regional events, have set the DPRK's economy in what most observers agree is either a downward spiral or (at best) stagnation.

The DPRK is a nation of, depending on the source of the information, somewhat under or somewhat over 22 million people (as of 2000), with approximately 60 percent of the population living in urban areas. The population growth rate for the nation had been estimated near 1.8 percent per year as of 1990, but the DPRK population has in fact probably been decreasing, overall, in the last decade or so[2]. DPRK population centers, as well as the bulk of industry and agriculture, are concentrated in the coastal plains on both the east and particularly west coasts of

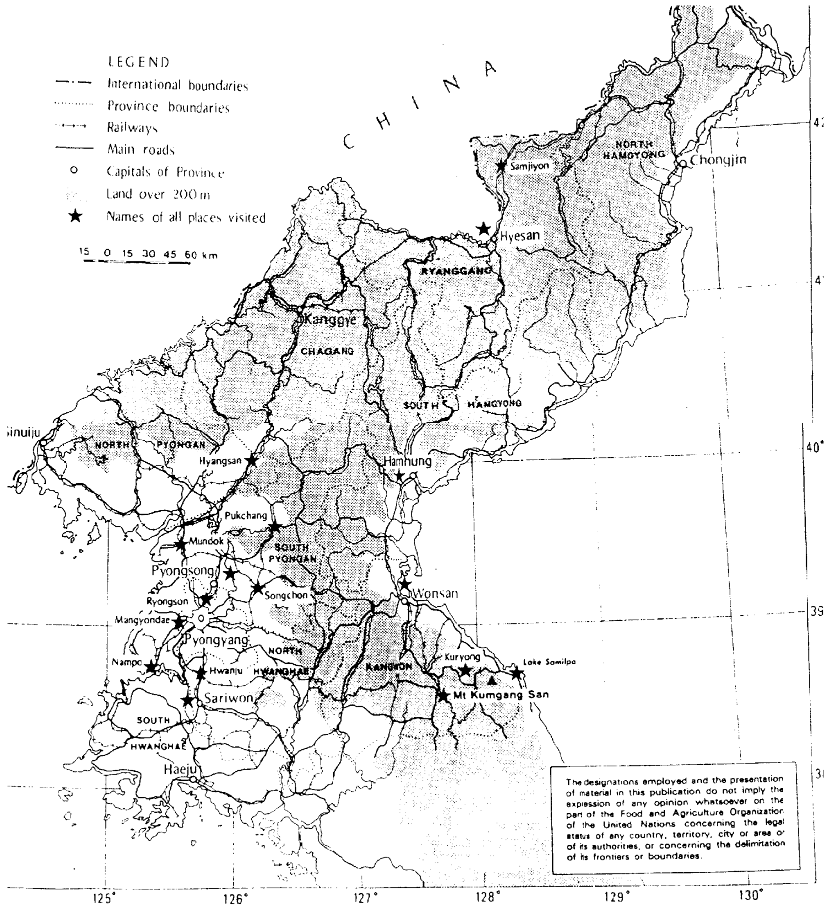
---

Institute (prepared for Northeast Asia Economic Forum), 1997); a discussion of the rural energy crisis in the DPRK, and of measures that might be taken to rebuild rural energy and agricultural infrastructure in the country (J. Williams, D.F. Von Hippel, and P. Hayes, Fuel and Famine, Rural Energy Policy Options in the DPRK, Nautilus Institute, March 2000); and a long-term project, which to date has included three missions by U.S. engineers to the DPRK, to provide wind-powered electricity generation, electricity storage, efficient electric end-use equipment, and water pumping windmills to a flood-affected village in a rural area of the DPRK. In the latter project, Nautilus engineers have worked (and played) side-by-side with North Korean counterparts to construct facilities in the village. The project has also included what is to our knowledge the first systematic survey of rural energy use ever carried out in the DPRK. (J. Williams et al, “The Wind Farm in the Cabbage Patch”, Bulletin of the Atomic Scientists, May/June 1999).

[2] Census data from the DPRK are notoriously unreliable, when available.

the peninsula. The interior of the peninsula is generally rugged and mountainous. A map of the DPRK is provided as Figure 1.1.

Figure 1-1: Map of the DPRK



The government of North Korea is a one-party, socialist system. North Korean politics has, since the formation of the DPRK, been dominated by the Kim family. Kim Il Sung, the "Great Leader", ruled the DPRK with a tightly controlled inner circle of advisors (Politburo) from just after World War II until his recent death.   His thought and writings form the primary basis of the DPRK political framework, which has at its root the principal of “Juch’e”, or national self-reliance[2].   The mantle of leadership has since passed to the son of Kim Il Sung, Kim Jong Il.

The economy of North Korea, hobbled by years of Japanese occupation in the period prior to World War II, was shattered by the Korean War. Through political and economic discipline, and strategic aid from East Bloc allies, Kim Il Sung and his government were able to rebuild the North Korean economy by focusing on economic autarchy and heavy industries such as the extraction and refining of minerals. A series of national plans set output goals for a number of key commodities such as iron and steel, coal, electricity, cement, fertilizer, and grain. Collectivized agriculture and state-owned companies reportedly account for about 90 percent of all economic activity[3]. Key economic resources for the DPRK include:

- A well-trained, disciplined work force;
- An effective system for dissemination of technologies;
- The ability to rapidly mount massive public works projects by mobilizing military and other labor; and
- Extensive reserves of minerals.

The impressive economic gains of the 1960s and early 1970s, however, were slowed in the 1980s and especially early 1990s as a result of a number of factors, including:

- Foreign debt incurred in purchasing industrial equipment and oil.
- The global "oil crises" of the 1970s, and the slowdown in the global economy.
- The decline and eventual collapse of the Soviet Union, and the resulting reduction in Soviet/Russian aid to the DPRK.
- Poor grain harvests in the early 1990s.

Estimates of gross national product (GNP) per capita in the DPRK are complicated by the fixed (but arbitrarily set) exchange rate between the DPRK Won and hard currencies (such as the US dollar). Estimates of per capita GNP in 1990 range from an official value of about US $2,000 (probably in 1990 dollars), down to estimates in the range of US $1,000 by international observers[3].

Although North Korea has raw materials, particularly minerals, that are of interest to trading partners, it has produced few finished goods (with the exception of armaments) that are of high enough quality to attract international buyers. The DPRK's major trading partners as of 1990—the reference year for the time series in this study—were China, Russia, Iran (reportedly trading oil for armaments), and Japan. The DPRK has limited trade with other Asian nations, as well as with some European and other nations. The value of imports to North Korea exceeded that of exports by $600 million in 1990. Trade in 1991—both exports and imports—was down markedly from 1990[4].

1.2.2. Changes in the DPRK since 1990

The economic, if not social and political, landscape in the DPRK has changed markedly during the 1990s. In the early 1990s, the North Korean government openly admitted the country's failure to achieve the economic goals of its most recent seven-year plan[5]. Although little data have been available from inside the DPRK, information from outside observers of the country indicates that the North Korean economy was at best stagnating, and most probably in considerable decline, through the mid-1990s[6]. We have reason to believe that this economic decline has been both a result and a cause of substantial changes in energy demand and supply in North Korea over the last decade. Recently observers of the DPRK economy have suggested that at least a modest improvement has taken place in recent years—ROK sources, for example, say that the DPRK economy grew approximately 6 percent in 1999, and another 1.3 percent in

---

[3] 1990 GDP estimates for DPRK using a "purchasing power parity" measure of production and value are closer to $2000 per capita.

2000[7]. Other observers, however, tend to argue that most of any economic upturn in the DPRK economy appears to be driven by food and other aid from abroad[4].

Among the energy-sector changes on the supply side in the DPRK since 1990 have been:

- A vast drop in imports of fuels (particularly crude oil and refined products, but coal and coke as well) from the Soviet Union and Russia. An index of these imports declined from a value of over 140 in 1987 to 8.7 in 1993, and crude oil imports from Russia in 1993 were on the order of one-tenth what they were in 1990[8], and have fallen to practically zero since.

- A steady decline in the exports of coal to China between 1988 and 1993, with the value of those exports receding in 1993 to approximately a tenth what they were in 1990. This fall may be a sign of reduced output in the DPRK coal industry, particularly as coal imports to North Korea from China have remained near the same level (in dollar terms) from at least 1982 through the early 1990s[9].

Oil import restrictions have reduced the availability of refined products in the DPRK. These problems arose partly (if indirectly) from economic sanctions related to the nuclear proliferation issue (see below), and partly from North Korea's inability to pay for oil imports with hard currency. This lack of fuel, particularly for the transport sector, has probably contributed to the DPRK's economic malaise since 1990. Another factor contributing to the decline in the country's economic fortunes has been the inability (again, partly due to lack of foreign exchange, and partly due to Western economic sanctions) to obtain key spare parts for factories, including factories built with foreign assistance and/or technology in the 1970s[5]. Also, as mentioned above, there has been, in the years since 1990, a virtual halt in economic aid, technical assistance and barter trade on concessional or favorable terms from Russia and other Eastern European nations. This reduction, coupled with a sharp decline in similar types of assistance from China (including, in the last several years, a sharp reduction in crude oil shipments to the DPRK), had resulted in a total estimated loss of aid to the DPRK economy of more than $ US 1 billion per year[10] by the mid-1990s. The DPRK's trade deficit as of 2000 stood at $US 856.88 million[11].

---

[4] For example N. Eberstadt (2001), <u>If North Korea Were Really "Reforming", How Could We Tell—And What Would We Be Able To See?</u> states "...official claims of 'turning the corner' and 'completing the Forced March' notwithstanding, the DPRK remains in dire economic straits.". Eberstadt goes on to cite the UN Food and Agriculture Organization's finding that DPRK cereal production in 2000/2001 "is expected to be fully a third below the level of 1995/96", and asserts, based in part on the DPRK's meager reported export earnings in the first half of 2001, that "The country's export capabilities are likewise in a state of virtual collapse…".

[5] As of 1995 the DPRK's trade deficit was estimated at $879 million (United States Department of Energy Energy Information Administration (UDOE/EIA, 1996), <u>Country Analysis Brief, North Korea</u>. Part of USDOE/EIA World-wide Web site, WWW.eia.doe.gov/emeu/cabs/nkorea.html.)

1.2.3. Impacts of flooding and food shortages

The economic difficulties mentioned above have been exacerbated by an untimely combination of climatic events. The early 1990s saw a series of poor grain harvests in the DPRK. Compounding these difficulties, 1995 and 1996 brought severe flooding to many areas of the DPRK, washing away topsoil from areas at higher elevation, and burying many areas of crucial low-lying farmland in tens of centimeters of silt or sand[6]. An additional blow to North Korean agricultural production was leveled by a tidal wave, caused by a typhoon at sea, that swept over and heavily damaged a long dike on the west coast of the DPRK in September of 1997, inundating hundreds of thousands of hectares of rice fields. The combined effects of flooding and poor harvests—even before the damage from the tidal wave is factored in—have been a food shortage severe enough to spur the DPRK government to take the unusual step of publicly requesting food aid from the international community. Many observers of the DPRK, particularly in areas away from the major cities, report that official rations are far from sufficient to meet dietary requirements, that people are supplementing their rations with tree-bark, grass, and whatever other semi-edible materials they can obtain, and that those people seen in the streets are thin and weak. It is reported that in recent years official food distribution channels no longer function in many cities in the DPRK, especially in northern areas of the country, and that as a result residents are turning to unofficial "farmers' markets" for much of their food. The consensus is that substantial (but unknown) numbers of citizens have starved in recent years, and hundreds of thousands more (at least) are malnourished and are gravely at risk. Given recent drops in the amount of food aid being donated to the DPRK, the World Food Programme warned that it was facing a shortage of 611,000 tons of food this year.[12] The United States recently announced it would donate 100,000 tons to help alleviate this shortage.[13]

Apart from the overriding human concerns associated with the food shortage, the slow starvation of the DPRK populace cannot help but decrease economic production still further, as poorly-fed people are less capable of work[7]. The flooding of 1995 and 1996 damaged an unknown number of irrigation dams and canals. Additional flooding in 1999 damaged both agricultural and industrial areas. Cumulative damage to and "wearing out" of agricultural and other infrastructure, coupled with damage to farmlands (both related to climatic events and long-term degradation), means that it may be years before the DPRK is able to grow enough food to feed its populace again, even if the required agricultural inputs (fertilizer, machinery, and fuel for the machinery) do become more available.

---

[6] One such affected region is the Sinuiju area, where, after the 1995 floods, "…sand poured in from the Yalu River and destroyed all the rice fields in the region" (Bernard Krisher "Urgent Proposals To Get Food & Drugs To North Korea", extracted in Northeast Asia Peace and Security Network Daily Report, 30 May 1997. Nautilus Institute, Berkeley, CA, USA.

[7] Another way in which the food shortage will likely affect the economy is that scrap metal, some taken from industrial facilities, is apparently being used as barter to obtain food via cross-border trade with China (Korea Times, "N. KOREA BARTERS SCRAP IRON FOR CHINESE FLOUR, CORN," Beijing, 05/18/97). Although the extent to which operational industrial facilities are being dismantled to trade for food is unknown, we find it conceivable that even if the DPRK does manage to obtain the needed inputs and investment to restart industrial production, many plants will be found to be inoperable due to key missing (sold for scrap) parts. In the same vein, there have also been reports from defectors that North Koreans have cut pieces of telephone and electrical wire to barter the copper in them to Chinese smugglers in exchange for food and other items (Korea Times, "RUMORS OF WAR RAMPANT IN N. KOREA," 05/23/97).

1.2.4. Current status of international relations and potential impacts on the DPRK economy: negotiations, food aid, and the Agreed Framework

The DPRK maintains relatively good relations with China, Russia, and the countries of the former East Bloc, although, as noted above, direct assistance and concessional trade from these countries (except China) has been substantially suspended in recent years. Relations with Japan, the United States, and the Republic of Korea remain tenuous, with the last few years seeing cycles of apparent rapprochement scuttled by various political and military incidents. As of this writing, several sets of international negotiations with potential impacts on the DPRK economy are underway or under discussion:

- *Negotiations regarding the provision of food aid to the DPRK.* The DPRK has allowed international aid organizations, including the World Food Programme, International Federation of the Red Cross, and various European aid agencies to set up residence in Pyongyang. In recent years, aid workers have reported growing access to areas of the country outside the capital, although still well below the desired level. Recently, however, these organizations have been forced to scale down their operations due to a sharp decrease in donations. The largest donor governments have been the ROK, the United States, Japan, and the European Union. Russia also reportedly provided a large amount of food aid to the DPRK, although outside of official U.N. channels.
- *Talks relating to the "Agreed Framework"* (see section 1.4, below) under which the DPRK agreed to abandon its gas-cooled nuclear reactor program in exchange for an agreement by the US and the ROK to provide to the DPRK two pressurized water reactors and shipments of heavy fuel oil until the reactors are ready to run. An official groundbreaking for the reactors, attended by project personnel from several countries, was held in the DPRK in August of 1997, and work at the reactor site, though significantly delayed, is proceeding.
- *Bilateral US-DPRK talks* that were underway during the Clinton administration have been stalled since George W. Bush assumed the presidency. Recently, however, the DPRK agreed in principle to allow U.S. special envoy Jack Pritchard to visit Pyongyang, although a date has not yet been set. The DPRK would like to be removed from the U.S. list of terrorist-sponsoring nations, which would free it up to pursue aid from international financial institutions dominated by the United States.
- *Bilateral ROK-DPRK talks* have taken place on an on-again, off-again basis since the two Koreas held their historic summit meeting in June, 2000. The ROK has proposed several projects for economic cooperation, including connecting the two countries' railroad systems and building an industrial park in the border town of Kaesong. While the DPRK has agreed to these ideas in principle, it has done little to implement them in practice. The DPRK pulled out of the most recent meeting of the Inter-Korean Economic Cooperation Committee in protest over remarks made in Washington by Foreign Minister Choi Sung Hong.
- *Bilateral Japan-DPRK talks* have usually broken down over allegations that the DPRK kidnapped some 11 Japanese citizens, a charge that the DPRK denies. The most recent talks in April, 2002 resulted in an agreement by the DPRK to investigate the Japanese cases and to allow Japanese wives of North Korean men to visit their families. The DPRK hopes that normalization of relations with Japan would result in a substantial package of reparations for

Japan's colonial rule, similar to the aid that the ROK received in 1965, which helped fuel its industrialization.

- *Talks between the DPRK and EU nations* have resulted in normalization of relations with all EU member states except France and Ireland. Australia and Canada have also normalized relations with North Korea, and all of these countries have sent delegations to Pyongyang to discuss bilateral and multilateral projects. It is hoped that these countries can play a significant role in providing development aid and training to the DPRK.

Significant progress in any one of these areas of negotiation would likely lead to greater progress in all arenas, and, ultimately, to a gradual thawing of relations between the Koreas, the DPRK and Japan, and between the DPRK and the United States. Such an improvement in relations is a prerequisite for re-starting the DPRK economy, and, by extension, a prerequisite to implement significant changes in the DPRK energy system.

Another bilateral dialog is currently underway between the DPRK and Russia. These talks reportedly include discussions about restoring some of the DPRK's economic ties with Russia, and of Russian financial and technical involvement in specific DPRK energy and industrial projects, in particular the inter-Korean railway project and electrical grid interconnection between the countries. Given the historical economic relationship between the DPRK and Russia, and Russia's strong interest in revitalizing its own Far Eastern region, it is quite conceivable that Russia could play an important role in the rebuilding of the DPRK economy, particularly if the Russian economy becomes more robust.

1.3. Summary of the Overall Energy Situation in the DPRK

Overall energy use per capita in the DPRK is relatively high, primarily due to 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[8] use in the DPRK in 1990 was approximately 71 GJ per capita, approximately 3.1 times the per capita commercial energy use in China in 1990, and somewhat over 50 percent of the 1990 per capita energy consumption in Japan (where 1990 GDP per-capita was some ten to twenty times higher than the DPRK). This sub-section provides a brief sketch of the DPRK energy sector, and some of its problems. A much more detailed review of energy demand and supply in the DPRK in 1990, 1996, and 2000 is provided later in this report.

1.3.1. Energy demand—sectors, fuels, and problems

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 transport; 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 much smaller shares of the fuels supplies in the DPRK than they do in industrialized countries, due primarily to the minimal development of the commercial sector in North Korea. Wood and

[8] 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.

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

Key energy-sector problems in the DPRK include:

- *Inefficient infrastructure*: Much of the energy-using infrastructure in the DPRK is reportedly antiquated and/or poorly maintained. Buildings apparently lack insulation, and the heating circuits 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) are operated at less-than-optimal capacities (from an energy efficiency point of view).

- *Suppressed and latent demand for energy services*: Lack of fuels in many sectors of the DPRK 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 (probably particularly electricity) use, as residents, industries, and other consumers of fuels increase their use of energy services toward desired levels.

- *Lack of energy product markets*: Compounding the risk of a surge in the use of energy services is the virtual lack of energy product markets in the DPRK. Without fuel pricing reforms, there will be few incentives for households and other energy users to adopt energy efficiency measures or otherwise control their fuels consumption. 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.

1.3.2. Energy supply—resources, technologies and processes

North Korea'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. There is little, if any, coal cleaning in the DPRK. There are no operating oil wells in North Korea, although oil resources reportedly have been located offshore in DPRK waters. All crude oil and some petroleum products were imported (as of 1990) from Russia, China, and Iran, plus some purchases on the Hong 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 1995 and 1996 (and 2000), only one of the two refineries was apparently operating, and imports of refined products had not expanded sufficiently to replace the lost production. A third, smaller refinery on the West Coast of the DPRK reportedly operates sporadically when crude oil shipments are available.

1.3.3. Summary of electricity demand and supply

The estimated per-capita electricity demand in the DPRK in 1990 was about 1,400 kWh per capita. By comparison, overall 1990 electricity demand in South Korea was about 2,200 kWh per capita[14]. Per capita electricity consumption in the DPRK has declined very substantially since. 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 use.

Electricity generation is primarily hydroelectric and coal-fired, in approximately equal proportions, with a small amount of oil-fired electricity generation capacity associated with the oil refinery at Sonbong and in two other plants. Much of the generation capacity was installed in the 1970s and 1980s, although a significant portion of generation facilities—particularly hydroelectric facilities—date back to the Japanese occupation[9]. Many of the hydroelectric facilities in the DPRK are reported to be of the "run-of-river" variety, which means that their output is more subject to variations in stream flow than plants that rely on larger impoundments with greater water storage.

The DPRK has the coal resources necessary to expand thermal power generation, but it not clear that the coal mining or transport infrastructure is capable of supplying coal to power stations at a rate much greater than that prevailing in 1990. Given weather patterns in the subregion, North Korea probably has a significant wind power resource, as yet untapped (and largely unmapped). The DPRK also has some remaining undeveloped hydroelectric sites.

Power generation facilities are reported to be in generally poor, and often failing, condition and sometimes (because they are based on technologies adopted from China or the Former Soviet Union) not well adapted to the coal types with which they are fired. As a consequence, the generation efficiency of the thermal power stations in the DPRK is reportedly low. 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.

The system of electricity dispatching is inefficient, minimally or not at all automated, and prone to failure. Estimates of transmission and distribution (T&D) losses vary from an official 16 percent up to more than 50 percent, but any estimates of T&D losses are difficult to confirm, as there is minimal end-use metering in the DPRK[10].

1.4. Environmental, social, and political background

The DPRK energy sector in general, and the electricity supply system in particular, is a major source of environmental problems both within and—in the case of regional and global pollutants—outside the country. As such, the status of the environment has a significant bearing on the future development of the DPRK electrical system. Similarly, the social and political history and current situation constrains the options (and likely directions) for energy sector development. In the following paragraphs we present a very brief review of the environmental, political, and social setting for the DPRK energy sector[11].

---

[9] Many of the hydroelectric facilities built during the Japanese occupation were reportedly disabled or dismantled by the Japanese (during retreat from the Peninsula) or by the USSR, but were later refurbished with technical assistance and equipment from the USSR.

[10] That is, generally, power is reportedly simply provided to consumers without metering, so "sales records" as such do not exist.

[11] Additional discussion of the environmental situation in the DPRK can be found in D. Von Hippel and P. Hayes, "Environmental Problems and the Energy Sector in the Democratic People's Republic of Korea (DPRK)". Asian Perspective, Vol 22, No. 2, 1998, pp. 51 - 77.

1.4.1. Summary of environmental problems in the DPRK, including those associated with energy use

The DPRK occupies an area of 122.7 thousand square kilometers, of which roughly three-quarters is classified as forests, and 20 thousand km^2 (2 million hectares) are used for agriculture. With the exception of the coastal plains (primarily on the West side of the peninsula), the topography is rugged and mountainous. North Korea's forests were overexploited during the Japanese occupation, and badly damaged during the Korean War; as a consequence, they are not well-stocked, and only about a third of the area is classified as "productive". A significant reforestation effort has, however, been underway.

Rainfall in the DPRK averages slightly over one meter per year, and the climate is temperate, with hot, humid summers and cold winters. A branch of the Northern Pacific Equatorial Current raises the temperature of Korean coastal and near-shore waters, resulting in highly productive fisheries.

Although the North Korean leadership has declared that environmental protection is of paramount importance[12, 15], observers have noted a host of environmental problems in DPRK. Among these problems are:

- Industrial pollution of rivers;
- Urban air pollution (including sulfur and nitrogen oxides, the precursors of acid precipitation) from industrial facilities and virtually uncontrolled combustion of coal in residential, industrial, and power plant boilers[13];
- Indoor air pollution from domestic combustion of coal and biomass fuels;
- Pollution of surface- and groundwater from agricultural practices (fertilizer and pesticide application, irrigation);
- High per-capita greenhouse gas emissions (from high per-capita coal use);
- Pollution of waters by drainage from mines; and
- Potential environmental problems stemming from national efforts to fill tidal flats on the western side of the peninsula to create new farmland.

North Korea suffers from a lack of sufficient trained personnel and analytical equipment for use in enforcing existing environmental laws, meaning that environmentally-sound practices are likely to be sporadic at best. In the short run, the absence of an effective regulatory infrastructure means that the extent to which the DPRK takes environmental considerations of any kind into account in planning and operating its energy system is likely to be externally, rather than internally, motivated. For example, progress in making coal-fired power stations less polluting is much more likely if environmental performance is tied to technical aid (from the United States, the ROK, the United Nations or others).

[12] Kim Il Sung "set forth the principle that the problem of environmental protection should be taken into account ahead of socio-economic development and that every possible measure should be taken for environmental protection ahead of production and he has seen to it that the principle be kept with credit".

[13] This problem has been notably reduced in recent years with the considerable reduction in industrial activity and overall energy use in the DPRK.

1.4.2. The impact of the 1995/1996 floods and the food crisis

The floods of the last two years, apart from causing damage to irrigation structures and possibly major damage to hydroelectric facilities, have likely exacerbated the process of soil depletion that was already well underway. As noted above, sediment from upland areas has been deposited on important rice paddy areas. Some 90,000 hectares of paddy land were reported to be under large deposits of sand and debris as of 1996, and fuel is lacking for the excavation machinery and other equipment needed to rehabilitate paddy land and restore irrigation systems[16]. It seems likely (though as yet only conjecture) that the sediments deposited by the floods includes industrial and agricultural pollutants that may poison soils in some areas for years to come—although the flooding may also have served to flush pollutants from and rejuvenate soils in some areas. Sediment loss from upland soils was probably higher that it would have been due to the poor condition of forest stocks—forests in good condition help to prevent erosion.

The food shortages exacerbated (in large part) by the floods[14] are also likely to have a long-term impact on forests and on other vegetation. Lack of agricultural products have reportedly sent North Koreans to foraging intensively for edible and semi-edible wild plants. There have been reports of people eating preparations made from bark stripped from trees. These practices are likely to at best expose trees to greater risk from pests, diseases, and other environmental threats, and at worst, kill the trees, further exposing areas to erosion problems. Over-exploitation due to desperate foraging may also endanger or extinguish rare or threatened species of flora and fauna in the DPRK's natural habitats.

1.4.3. DPRK agricultural conditions and food situation since 1996

In recent years, the DPRK's agricultural situation has shown some signs of improvement. The World Food Programme and the Food and Agriculture Organization reported that the DPRK produced 3.54 million metric tones of food in 2001-2002, a 38 percent increase over two years earlier and the most since 1995. This included an estimated 1.35 million tons of rice (milled basis), 1.4 million tons of corn, and 100,000 tons of wheat. That left the DPRK with an estimated food deficit for 2001-2002 of around 1.47 million metric tons, down from 2.2 million tons a year earlier[17]. The increased food production has not been sufficient to make up for the drop in donations that resulted in part from a shift in international attention to the situation in Afghanistan.

1.4.4. The DPRK social and political system, and its influence on the energy and electricity sector

The "Juch'e" or autarchic philosophy of the DPRK government has shaped the electricity and energy sectors in the DPRK. Development of indigenous resources—notably coal—has taken precedence, as has "reverse engineering[15]" and other techniques of developing technologies that can be produced domestically. Another major factor in shaping the DPRK'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 often providing

[14] There is some evidence that the food shortages of recent years are in large part a result of structural problems in the DPRK agricultural sector that date back to 1990 or before.

[15] 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.

equipment for, constructing, and even operating thermal power plants, industrial plants, and many other elements of the DPRK 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 DPRK operate much less efficiently than comparable (current) processes in other countries, contributing to the overall inefficiency of the DPRK economy[16].

The use of oil for electricity generation is limited primarily to a single heavy-oil-fired power plant associated with an oil refinery. Some smaller older diesel-engine generators may be in use as well[17], and at least one fairly new diesel-type generator has been installed in an industrial setting. We have not heard reports of any gas-fired generation and the DPRK lacks facilities for importing liquefied natural gas, or LNG. 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.

The North Korean workforce is literate, disciplined, and hard-working; these attributes have been key in allowing the DPRK to make the economic strides that it did during the phase of heavy industrialization in the two decades following the Korean War. The DPRK workforce, however, suffers from a lack of technological training as a result of North Korea's political isolation. 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 may present problems in retraining workers for new, higher-technology jobs (for example, to make goods that would be competitive in export markets). 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.

The DPRK government has shown a preference for massive construction projects. This predilection, plus the ability to muster large work-forces rapidly, is helpful when constructing hydroelectric impoundments and barrages (sea-walls), as well as in conducting other large public works such as recovering from the floods, but is less helpful in constructing smaller, more specialized, and more efficient equipment. The large outlays (reportedly up to $890 million per year[18]) by the government 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 potentially economically-active males 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 DPRK economy[18].

---

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

[17] Diesel generators were reportedly often incorporated into industrial plants built with USSR assistance in order to provide back-up power.

[18] This in addition to the direct financial outlays for maintenance of the armed forces.

1.4.5. The "Agreed Framework" and KEDO

As a condition of the October 1994 Agreed Framework signed by the governments of the United States and the Democratic People's Republic of Korea (the DPRK), the DPRK is to be supplied two pressurized-water-type light-water nuclear reactors for electricity generation (referred to as PWRs) in exchange for abandoning its existing graphite-moderated nuclear research reactors and taking further steps to comply with nuclear safeguards . As noted above, work at the reactor site (at Sinpo in the DPRK) began in August of 1997[19]. Until the reactors are completed, the Korean Peninsula Energy Development Organization (KEDO) 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 each "HFO year" (not necessarily corresponding to calendar years) since then have totaled the agreed amount[20]. The oil provided by KEDO is intended to be used to fuel electricity generation and district heating facilities.

This transfer of PWR technology under the Agreed Framework was 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, the Framework was attractive to other nations (led by the United States) as a means to start the thawing of relations with the DPRK, as a way to lessen the probability of nuclear weapons proliferation, and as a means to exert better international control over the DPRK nuclear program. Funding for the PWR transfer is from the Korean Peninsula Energy Development Organization (KEDO), formed in the mid-1990s, which obtains its financing mostly from the ROK, with some additional inputs from the United States (particularly for HFO purchases), Japan (US$1 billion) and the European Union[19]. Although energy efficiency and renewable energy measures could conceivably provide the same energy services to the DPRK economy as would the PWR, and could do so on at least a similar time scale and for lower cost[21], energy efficiency measures are not politically substitutable for the PWR transfer[20]. The PWR transfer—or some similar arrangement—is, however, a necessary first step to a political opening by North Korea, an opening that could lead to investments—including investments in energy efficiency—that will serve to integrate the economy of the DPRK with the other economies of the region. This integration would enhance stability and security in the region in the medium and long-term, and is the underlying logic implicit in the hopes of US and ROK policy-makers to achieve a "soft landing" for the DPRK economy and polity.

1.5. Guide to Remainder of Report

The remainder of this report is organized as follows:

- In **Chapter 2**, we describe the key assumptions and background information that we used in preparing energy supply/demand balances for the DPRK for the years 1990 and 1996. The key results and uncertainties of our estimates are presented as well.

---

[19] Though funding for KEDO has come from the countries indicated, the DPRK will be obliged to repay the funds loaned to build the PWRs. KEDO and the DPRK signed an agreement on June 24, 1997, specifying penalties to the DPRK if the DPRK fails to repay the loan (http://www.kedo.org/pdfs/ProtocolNonPayment.pdf).

[20] For a much more thorough discussion of this issue, see D. Von Hippel et al. (2001), Modernizing the US-DPRK Agreed Framework: The Energy Imperative. Nautilus Institute Report, February, 2001. Available at http://www.nautilus.org/papers/energy/ModernizingAF.pdf.

- In **Chapter 3**, we give overviews of the methods, results, assumptions, and uncertainties of our analysis of the DPRK supply and demand for energy resources and fuels in the year 2000.
- In **Chapter 4**, we provide qualitative assessments of the potential future of the DPRK energy sector, and suggest policies that the DPRK might undertake to improve the performance of its energy sector. We also briefly address the role of regional cooperation in addressing the DPRK electrical sector, including a summary listing of what we see as the key issues and options for constructive cooperation between the DPRK and the countries of Northeast Asia (and other regions) on energy-sector and related issues. Our suggestions as to attractive energy sector technologies and processes for energy sector redevelopment in the DPRK are also outlined in summary fashion.
- **Attachments** to this report present detailed results of the estimates of DPRK supply and demand in 1990, 1996, and 2000, and also present details on the data, assumptions, and analytical approach used in preparing those energy balance estimates.

2. Estimated 1990 and 1996 Supply/Demand Energy Balances

As a backdrop to the cooperation strategies and other recommendations discussed in Chapter 4 of this Report, this Chapter describes the inputs to and results of our estimated 1990 and 1996 energy demand-supply balance for the DPRK. In this Chapter we provide a brief description of the overall approach we used in assembling the estimated supply and demand balance for the DPRK in 1990 and updating it to 1996 (section 2.1). Next, we provide more detailed descriptions of the estimation procedures used for each major part and sub-part of the balance:

- The final demand for the fuels used in the North Korean economy in 1990 and 1996, by economic sector and (in some cases) subsector, is detailed in section 2.2.
- Section 2.3 covers energy supply (domestic energy resource production, imports, and exports) for non-electric fuels
- Fuel transformation processes (except for electricity) are described in Section 2.4.

The final section of this chapter, section 2.5, presents our estimated 1990 and 1996 DPRK energy supply and demand balances, and discusses some of the key results and uncertainties in the balances, their ramifications, and the questions that they poses for follow-up research. The approach used here, as well as the discussion that follows, are in large part taken from our earlier works. The reader should note, however, that the 1990 and 1996 balance estimates, and the detailed results reported, have changed somewhat from those presented in our earlier reports as we have incorporated recently-obtained information about the status of the DPRK energy sector in 1990 and 1996.

2.1. Goals and approach in preparing 1990 and 1996 supply/demand balance

To assess measures to improve the energy sector of the DPRK (or any country), including the potential for energy efficiency improvements or for implementation of renewable energy sources, it is first necessary to learn something about the way that energy is supplied and used in the area under study. One way to obtain a single-sheet "snapshot" of the energy system in a particular country in a given year is to assemble a **supply-demand balance**. This type of table lists the sources of the fuels used in the economy, shows the processes that produce or refine primary fuels for end-use consumption (such as electricity generation facilities), and lists the final demands for fuels, typically by sector.

The work presented in this document builds on Nautilus research, funded by W. Alton Jones Foundation, which culminated in a draft report entitled The Prospects for Energy Efficiency Improvements In the Democratic People's Republic Of Korea: Evaluating and Exploring the Options, plus further research in 1997, funded by the Northeast Asia Economic Forum/East-West Center, that produced Demand and Supply of Electricity and Other Fuels in the Democratic Peoples' Republic of Korean (DPRK). In our 1995 work, we prepared an estimated energy supply/demand balance for the DPRK for the year 1990 that synthesized the information available to us on the North Korean economy and energy sector. In the 1995 report, the energy balance results were used to estimate the (by any measure, considerable) potential for energy-efficiency improvements in the DPRK. Our 1997 work produced an estimated energy balance for 1996, and used it as the starting point for quantitative energy "scenarios[21]" for the DPRK for 2000 and 2005. In preparing the 1990 energy balance estimate, we:

- Collected available energy and other data on DPRK. The documents assembled included international and regional publications providing statistics (energy, industrial and agricultural output, infrastructure) on the DPRK; documents (in Korean) on the DPRK energy and economic situation obtained from South Korean (ROK) studies and other sources such as Russian analysts; official statistics provided by the DPRK government; historical documents on energy use in ROK; and other documentation from the authors' files.
- Collected energy statistics and other energy-sector data on economies that are likely to be similar, in some ways (such as types of infrastructure) to that of the DPRK. This process included collection of energy sector intensity data from the international literature[22] for the People's Republic of China, the Former Soviet Union, and the countries of Eastern Europe.
- Synthesized the information available and organized it by balance element (supply, transformation, demand), by fuel, and by subsector (when possible). We further categorized the types of information we collected as direct data on the energy system of the DPRK, including the *amount of energy produced or consumed*, and capacities of key infrastructure; data on *activities* relevant to energy use in DPRK, including the physical output (tonnes of steel produced, for example) in key subsectors, and other physical, social, and demographic factors such as population and agricultural land area; and data on the *intensity* of energy use. In the case of energy intensities in particular, very little information specific to the DPRK was available, so analogous and "placeholder" data from other countries, usually China or the former Soviet Union, were often used.

[21] In general, at present, Nautilus uses the term "scenario" to refer to fictional, typically qualitative narrative "snapshots" of what the future might hold based on uncertainty in key parameters, whereas "path" or "pathways" present linear, often quantitative descriptions of future conditions that are derived from current conditions, assuming certain changes. Based on these definitions, the 2000 and 2005 analyses contained in our 1997 work should be referred to as energy paths, but at the time we referred to them as "scenarios".

[22] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

The detailed inputs to and results of our 1995 work are presented in the report described above. This report was disseminated widely to specialists on Korea and on energy analysis in developing countries, with briefings in Washington, Tokyo, and Seoul. Copies of this earlier study were supplied also to DPRK authorities. The 1990 energy balance produced as above was revised to reflect comments on the original 1995 study and information recently received. It was then used as the starting point for estimating and projecting year 1996, 2000, and 2005 energy supply and demand, as described below.

Countries maintain statistics on energy supply and demand at differing levels of detail and aggregation; some have very good statistics, while others do relatively little data gathering, and what information does exist is of poor quality. These differences are often reflected in international compendia of energy statistics, such as the IEA/OECD Energy Statistics and Balances, which rely on data from the various countries themselves, as well as other sources[23]. In the case of the DPRK, it is probable that fairly good statistics on energy supply and demand do exist, but these data are probably in many different hands, and may not have been assembled to provide a coherent picture for the DPRK energy economy as a whole[24]. In addition, the North Korean government is loath to provide data to outsiders[25]. As a consequence, our efforts to assemble an energy supply and demand balance for DPRK had to rely on what few official statistics were available, augmented by data from a host of other sources, as detailed below.

Although the process that we followed in evaluating energy supply and demand in the DPRK is bound to produce energy balances that "fits" the DPRK poorly in some areas, it is our hope that in future collaboration with DPRK energy experts we will be able to use the balance described and presented below as a starting point to develop better information for use by both the international community and by the DPRK itself.

2.1.1. Study approach

Our approach in preparing an estimated 1990 supply-demand balance for the DPRK proceeded in several steps, as follows:

1. Collect available energy and other data on the DPRK. The documents assembled (most of which are referenced in the bibliography to this study) included:

   - International and regional publications providing statistics (energy, industrial and agricultural output, infrastructure) on the DPRK.

   - Documents (in Korean) on the DPRK energy and economic situation obtained from South Korean (ROK) studies and other sources such as Russian analysts.

---

[23] For the case of the DPRK, the IEA (International Energy Agency) had not (as of 1995) significantly updated its country-specific energy balances and other statistics for several years, as it has judged the incremental data that has been available to it to be untrustworthy (IEA, John Soderbaum, personal communication, 1995). In addition, the DPRK energy balances available from the IEA are at a highly aggregate level, with very little sectoral detail.

[24] Those familiar with the operation of the DPRK bureaucracy suggest that probably no one in the DPRK, with the possible exception of Kim Jong-il and a few of his closest advisors, has statistics that describe the entire span of the DPRK's energy economy. Any given government or Party official would have custody of statistics bearing only on his or her direct responsibilities, and no more. In addition, reports are reportedly frequently altered as they are passed up the chain of command in order to present to supervisors a rosier picture of, for example, energy production. These alterations mean that when and if the overall statistics for the economy are actually compiled for top officials, they are likely to be in error.

[25] This applies especially to those from outside DPRK, but probably applies to the internal sharing of information, for example, between government organizations, as well.

- Official statistics provided by the DPRK government.
- Historical documents on energy use in the ROK.
- Other documentation from the authors' files, and personal conversations and correspondence with others interested in DPRK issues.

2. Collect energy statistics and other energy-sector data on economies that are likely to be similar, in some ways (such as types of infrastructure) to that of the DPRK. This process included collection of energy sector intensity data from the international literature[26] for the People's Republic of China, the former Soviet Union, and the countries of Eastern Europe.
3. Synthesize the information available and organize it by balance element (supply, transformation, demand), by fuel, and by subsector (when possible). We further categorized the types of information we collected as:
   - *Direct data on the energy system* of the DPRK, including the amount of energy produced or consumed, and capacities of key processes (including power plants)
   - *Data on activities relevant to energy use in the DPRK*, including the physical output (tonnes of steel produced, for example) in key subsectors, and other physical, social, and demographic factors such as population and agricultural land area.
   - *Data on the intensity of energy use*. In this case, very little information specific to the DPRK was available, so analogous and "placeholder" data from other countries, usually China or the former Soviet Union, were often used.
4. Use the data collected to estimate energy supply and demand by fuel, transformation process, sector and subsector, incorporating judicious (it is hoped) assumptions and placeholder values where necessary. These estimates have been prepared in an easily-modified Microsoft Excel "workbook" of many linked "spreadsheets" covering the supply of and demand for energy, so that as more information becomes available, from DPRK officials or others, our balance can be updated and improved.

We chose 1990 to be the base year for our estimated supply/demand balance for several reasons. First, it is sufficiently recent to pertain to current conditions, but sufficiently far in the past that we can expect to find relatively complete energy and economic statistics. Second, 1990 represented a watershed year for the DPRK economy, in that after 1990 the continuing withdrawal of financial and other aid, as well as trade credits, from the former Soviet Bloc has contributed to a spiral of decreasing production and consumption in virtually all sectors. As a consequence, we felt that 1990 was a reasonable choice to represent a North Korean economy operating on a roughly "business as usual" basis[27].

---

[26] In particular, the Energy Analysis Program at Lawrence Berkeley Laboratory, Berkeley, California, USA.

[27] It has been argued that 1989 was actually the peak year for the DPRK economy, and that the DPRK's spending (on housing, sports venues, monuments, and other items) in hosting the international Youth Festival in Pyongyang reduced needed investment in other key sectors (including the energy sector), contributing substantially to an economic decline that started in 1990 ("Energy 'Crisis' Threatens Economy", Pukhan (Seoul, ROK) March 1993, pages 39-45, by Naeoe Tongsin reporter Kim Sang-hwan). Economic activity in the DPRK in 1990 was apparently slightly less than in 1989.

The output of steps 3 and 4 above are synthesized as part of the Workbook titled "Estimated/Projected Energy Supply/Demand Balances: Democratic People's Republic of Korea (DPRK)", which is provided as Attachment 1 to this report. An additional workbook, used to prepare estimates of annual fuel use in the DPRK Military, is provided as Attachment 2. Though the remaining sections of this chapter provide detail on how the elements of the estimated supply/demand balance were assembled, the reader is urged to refer to the Annexes for additional information and specific references.

An estimate of the potential for energy efficiency and renewable energy measures in the DPRK was discussed in some detail in the 1995 report mentioned above and in other papers prepared by the authors, but is not discussed further in this report[22].

Our overall approach to preparing a DPRK energy supply-demand balance for 1996:

- Starts with the estimates of demand and supply prepared above for the 1990 "base year"
- Modifies the 1990 estimates of demand for electricity and other fuels to reflect reports of recent changes in conditions in the DPRK. These included population growth, reduced availability of oil products, observed changes in the transport system, and reported reductions in industrial, agricultural and fisheries output.
- Revises our 1990 estimates of electricity supply to meet 1996 electricity demand and to reflect information about recent changes in thermal and hydroelectric generating capacity.
- Estimates 1996 oil supply in a way that reflects available information, including the capacities, product slates, and utilization of the oil refineries in the DPRK, and quantities of refined products reportedly imported during 1996.
- Revises oil products demand as initially estimated to meet the overall supply for each of the major classes of oil products (heavy fuel oil, diesel oil, gasoline, and kerosene).
- Sets the level of coal and biomass supply to meet demand, re-adjusting supply of other fuels as necessary to produce a rough balance in overall supply and demand.
- Evaluates the implications for demand for heavy fuel oil supplied by KEDO.

In updating our 1990 energy balance to 1996, we contacted a number of specialists in DPRK energy issues and economics, including those who deal with North Korea in business and/or regularly visit there, to obtain their data, thoughts and observations on recent developments the DPRK. Except where explicitly cited in the notes presented in Attachment 1 or in this chapter, these sources have chosen to remain confidential.

Key changes in the DPRK energy sector between 1990 and 1996 included:

- A reduction in the supply of oil products due to the virtual cessation of crude oil supplies from the Former Soviet Union.
- A considerable reduction in industrial production, which has reduced demand for (and thus production of) coal and electricity. Disentangling the causes of the decline in industrial output is difficult, but lack of oil products for industrial plants and goods transportation, lack of foreign exchange capital to pay for parts to repair industrial and mining equipment, and lack of international markets for DPRK goods all play a role.

- A reduction in transport generally, and a reduction in the use of oil products in the transport and agricultural sectors, with biomass and human labor (respectively) serving as partial substitutes for gasoline and diesel fuel.

The key assumptions and data used in preparing our estimated supply and demand balances for 1990 and 1996 are presented below by sector (for demand) and by fuel group (for supply). In each case, details of the data, calculations, assumptions, and sources used are presented in Attachments 1 and 2 to this report.

2.2. Summary of Methods and Data used to Estimate 1990 and 1996 Demand for Energy

Our estimated DPRK supply-demand balance breaks final fuel demand into the following sectoral categories:

- *Industry*, including a number of different subsectors;
- *Transport*, including road, rail, water, air and "non-specified" transport modes;
- *Residential*, which is further divided into the urban and rural subsectors;
- *Agricultural*, including field operations and a "processing/other" category;
- *Fisheries*, divided into fuel used in large ships and in processing and other operations;
- The *Military* sector, including accounting for each branch of the military (ground, air, and naval forces), and estimates for energy use in manufacturing military equipment and in military "buildings and other";
- The *Public and Commercial* sectors;
- *Non-Specified/Other* energy use, a placeholder category; and
- *Non-Energy* use of fuels.

Our methods for estimating the amount of fuel used in each of these sectors are discussed below.

2.2.1. The industrial sector in 1990

The industrial sector in the DPRK consists of a variety of energy intensive heavy industries and a number of light industries. To estimate energy use in this sector, our basic approach has been to gather all of the data on the physical output of specific industrial products that we could find, and multiply those physical output figures by per-unit energy intensities obtained mostly from studies of Chinese industries[28]. In a very few cases, we had and used anecdotal figures for energy intensities of key industrial plants in the DPRK, and in a few other

[28] An alternative approach would have been to obtain output figures expressed in monetary terms and use energy intensities per unit financial output. Unfortunately, the command-and-control nature of the DPRK economy, coupled with the fixed and essentially arbitrary exchange rate of the DPRK currency with hard currencies such as the dollar, make this approach unusable for most subsectors. Because of the lack of true markets in DPRK, the prices of goods have no particular relation to the actual value that the goods would have in a market economy (even a partial market economy like China's), thus cross-national comparisons of per-monetary-unit intensities are highly problematic (when one of the nations is North Korea).

cases we were able to use historical energy intensities from the Soviet Union as provided by a colleague in Russia[29].

It has been estimated that 60 percent of the industrial infrastructure in the DPRK was developed with substantial technical assistance from the former Soviet Union. As such, for many subsectors we realize that it would have been more appropriate to use energy intensity factors from the USSR experience than to use Chinese factors, but as of yet we have not had access to sufficient energy intensity data from the USSR to allow us to do so. Happily, our limited experience thus far has been that industrial energy intensities in the USSR and in China were often not terribly different.

Note that we have made the general assumption that industries in the DPRK are at least 10 percent more energy intensive than those in China whenever Chinese energy intensities were used, and 15 percent more energy intensive than USSR where Soviet energy intensities were used. Although these estimates are little better than guesses, we believe that they are appropriate given (among other reasons) A) the testimony of travelers to DPRK about the generally poor condition of North Korean industrial facilities; B) the vintage of most industrial plants in DPRK (few were built more recently than the 1970s, and some are leftovers from the Japanese occupation of the 1930s and 1940s); C) the low quality of much of the DPRK's coal, which contributes to poor combustion efficiencies; and D) reports of how Soviet industrial designs were "beefed up" to allow equipment to stand up under difficult conditions in the DPRK.

The output units and energy intensities we used for each industrial subsector, and their sources in the literature, are provided in Table 2-1. The specific methods used to derive fuel use for each subsector are detailed in the "Industry" spreadsheet of Attachment 1. Notes on the methods used for particular subsectors are provided below.

[29] Data for energy intensities in several industrial subsectors was provided to us by Dr. V. Kalashnikov (personal correspondence, September, 1997).

Table 2-1: Energy Intensity Assumptions by Industrial Subsector

ENERGY INTENSITY ESTIMATES USED IN ESTIMATES OF FUEL USE IN THE DPRK INDUSTRIAL SECTOR, 1990			
Industrial Subsector	Output Units	Coal Use Intensity (tce/Unit)*	Electricity Use Intensity (kWh/Unit)*
Iron and Steel	te crude steel	1.80	770
Cement	te clinker	6.88	110
Fertilizers--Ammonium	te NH_3	1.71	5,760
Fertilizers--Superphosphate	te P_2O_5	9.71	16,258
Other Chemicals--Carbide	te Ca Carbide	40.17	4,571
Other Chemicals--Caustic Soda	te	16.10	2,413
Pulp and Paper**	te	0.83	1,674
Other Metals--Zinc	te	2.72	4,228
Other Metals--Copper	te	1.88	1,364
Other Metals--Aluminum	te	2.11	17,655
Other Metals--Lead	te	2.96	203
Other Minerals***	te Magnesia	0.43	110
Building Materials--Glass	50 kg case	0.0339	34
Building Materials--Bricks	10,000 pieces	2.63	
Textiles--Printing and Dyeing	running meter	4.39E-04	
Textiles--Vinalon fiber	te	6.032	100

* Intensities shown are adjusted upward to take into account 10 and 15 percent "intensity inflators" used when applying energy intensities from Chinese and Russian data (respectively) to DPRK Industrial sub-sectors.
** Assumes that half of non-electric fuel use for paper production is provided by mill wastes and other wood by-products
*** Intensity shown for magnesite production is use of heavy fuel oil (not coal) per tonne of product.
Please see "Industry" section of Attachment 1 for detailed notes and data sources.

In the *Iron and Steel* industry, we have used an official estimate of steel production (assumed to be raw steel) that is somewhat higher than estimates from outside observers, and substantially higher than steel output estimates for the years since 1990. Although our method for calculating solid fuel consumption in this industry uses separate intensities for coal and coke use, we have not tried to account separately for non-energy use of coke, that is, for that fraction of the carbon in coke that becomes carbon in steel. For electricity consumption in the industry, we have used an energy intensity based on 1965 and 1980 values in Soviet steel plants (700 kWh/tonne)[23]. By way of comparison, intensities in "key, medium and small plants" in China as of 1987[24] were somewhat higher (890 kWh/tonne).

For the *Cement* industry we used official output figures from the National Report of DPRK to UNCED (dated 1992), which may be somewhat overstated, and a DPRK-specific coal-use intensity that is slightly higher than energy intensities for Chinese plants[25], and quite close to the 1980 intensity reported for cement plants in the former USSR.

Our data for the *Fertilizer* industry should be considered incomplete. Although we reviewed several different estimates for overall fertilizer production, there are several different nutrients provided by fertilizers, and several different compounds, delivering vastly different amounts of nutrient per unit weight of compound, for each nutrient[30]. We have used DPRK-specific coal- and electricity-use intensities for ammonium production, and an assumption that overall consumption of nitrogen fertilizer was 600,000 tonnes of nitrogen[26]. Depending on the formulations of nitrogen fertilizer used, this figure could be roughly consistent with other estimates of nitrogen and overall fertilizer use and production. Included in our calculus is an estimate of nitrogen fertilizer imports from the former Soviet Union, which reportedly amounted to about 100,000 tonnes (N basis) in 1990[31]. We have assumed that essentially all nitrogen fertilizer is based on ammonia produced via the DPRK-specific industrial process outlined (by a DPRK official)[27] and that the energy needed to convert ammonia to the other forms of nitrogen fertilizers used (including urea, ammonium nitrate, ammonium sulfate) is either included in the energy intensity we used, or is minimal relative to the energy needed to manufacture ammonia[32]. Based on a process diagram for the Hamhung Fertilizer complex, we estimate that roughly half of the coal used in ammonia manufacture is used as a feedstock. We categorized this fraction as a non-energy fuel use.

We have a rough figure for the production of superphosphate fertilizer (P_2O_5); have assumed that all superphosphate fertilizer is made from elemental phosphorous (which may not be correct); and have calculated the energy needed to manufacture superphosphate based on its phosphorous content. This method may overstate the energy needed to make phosphate fertilizers.

Although other fertilizers, including potassium fertilizers, are in use in DPRK, we have no data on production of these compounds. Because the volume of nutrients other than nitrogen (N) and phosphorous (P) required by plants is substantially less than the amount of N and P needed, the energy needed to manufacture these other fertilizers may be small relative to that required to make N and P fertilizer.

Energy use in our *Other Chemicals* category is limited to the coal, electricity, and petroleum products used in the production of carbide, a feedstock for the synthetic fibers and plastics industry, and caustic soda. Other compounds, including sulfuric and nitric acids, are produced in fairly large (though uncertain) quantities in the DPRK, but we were unable to locate suitable energy intensity data by the time of this writing. For carbide, we were guided by a process diagram for the Hamhung Chemical complex in DPRK that allows the calculation of rough coal and electricity use intensities. These values (particularly the coal use) appear to be slightly higher than similar values for Chinese industry. This fact is not entirely surprising, given the fairly unique coal-based process for carbide manufacturing used in this complex. The energy used in caustic soda (sodium hydroxide) manufacturing was calculated using USSR and Chinese figures for coal and electric energy intensities (respectively).

---

[30] For example, a tonne of anhydrous ammonia (NH_3) delivers approximately 820 kg of nitrogen, while a tonne of ammonium sulfate ($(NH_4)_2SO_4$) provides only about 210 kg of nitrogen.

[31] We have thus assumed that the DPRK produced about 500,000 tonnes (as N) of nitrogenous fertilizers).

[32] The electricity intensity of urea manufacture in China, for example, appears to be two orders of magnitude less than that for ammonia.

It has been reported (by DPRK officials[28]) that 30 percent of all oil (assumed to mean refined products) use goes into making carbide. This assertion would seem to be at odds with the coal-based process used at the Hamhung plant, and has also been contradicted by reports by others. As a result, we have assumed that carbide manufacture is not, in fact, a major use of fuel oil. If one assumes, however, that carbide is a precursor to virtually all plastics manufactured in DPRK, we may not have accounted for all of the carbide produced in the DPRK as of 1990. This possibility is supported by the fact that our assumed production of carbide by the Hamhung plant (350,000 tonnes) would likely be more than consumed solely in the production of textile fiber, given the level of DPRK textile production that we are using (see below).

In the *Pulp and Paper* sector, our estimates of paper output from the Economist Intelligence Unit[29] were coupled with coal and electric energy intensities from Chinese data, and includes a working assumption that 50 percent of the (non-electric) fuel energy needed required to produce pulp and paper is provide by wood wastes or other by-product fuels such as "black liquor". This assumption may or may not prove to be correct for the DPRK; we have seen reports that disposal in rivers of paper mill wastes in some areas of North Korea is a significant environmental problem, suggesting that by-products such as black liquor are in fact not used as fuels.

For the production of *Other Metals*, our analysis includes only Zinc, Copper, Lead, and Aluminum. Although these are apparently the non-ferrous (non-iron) metals produced in the greatest volumes in North Korea, they are hardly an exhaustive list. Chinese coal- and electricity-use intensities were used to estimate the amount of fuel used in producing these products. The electricity intensities used for all of these metals except aluminum also include the electricity needed to mill the metal ores. The collapse of the barter deal with Cargill Inc. in mid-1997 has been attributed to the DPRK's inability to supply the requisite quantities of zinc in exchange for wheat. This inability to produce zinc suggests that the minerals sector may be operating at very low capacities by 1997, or that fuels and/or minerals transport facilities may not be available to export the zinc.

In the *Other Minerals* category, we include magnesite, a refractory mineral present in abundance (and high quality) in DPRK, and produced in significant quantities (approximately one million tonnes) as of 1990[30]. For magnesite, we used a reported estimate for the intensity of heavy fuel oil use in DPRK magnesite refining[33], and assumed that electricity requirements per tonne of magnesite produced would be similar to that needed to produce chemically similar cement "clinker" from limestone.

In the *Textiles* industry, we started with estimates of the running meters of textiles produced in the DPRK, applied an average weight per meter figure (approximately a quarter kilogram per meter), and assumed that essentially all fabric was made of the "vinalon" fiber manufactured at the Hamhung complex (and other places). The majority of the coal used for textile production is thus used in manufacturing vinalon from carbide; some is also used in the printing and dyeing of fabrics. The coal and electric energy intensities of vinalon production were estimated based on a process flow diagram provided by DPRK officials[31].

---

[33] The value supplied, 300 kg oil equivalent per tonne of magnesite produced, is similar to estimates for coal use in magnesite production elsewhere in the world.

Although *Building Materials* can be expected to be an important subsector for DPRK industry, we could find no data for the DPRK output of key materials (other than cement, which is accounted for separately). In order to estimate placeholder fuel consumption values for two key products—glass and bricks—we made the assumption that the per-capita production of these items would be similar to that in China. Using per-capita figures derived from Chinese data, we applied a DPRK population estimate to derive figures for total glass and bricks production in North Korea, then applied Chinese energy intensity values for these products to estimate the use of coal and electricity by the subsector[34].

To provide sufficient demand to meet estimates of fuel supply, we included placeholder values for coal, petroleum product, and electricity use in *Non-specified* industries. These values amount to approximately 6, 18, and 8 percent of the total industrial demand for these fuels, respectively.

2.2.2. Changes in industrial output for 1996

The detailed calculations and data that we used to produce our 1990 estimates of energy use in the industrial sector, and to update them to 1996 and beyond, are presented in Attachment 1. Our estimates of 1996 industrial output relative to 1990 are presented in Table 2-2.

Table 2-2: Assumptions for Changes in Industrial Production in 1996

Subsector	**1996 Production Relative to 1990**
Iron and Steel (See Note 1)	36%
Cement (See Note 2)	32%
---- fraction of heat from heavy oil	10%
Fertilizers (See Note 3)	25%
Other Chemicals	30%
Pulp and Paper	30%
Other Metals	30%
Other Minerals	30%
Textiles	30%
Building Materials	30%
Non-Specified Industry--non-oil fuels	30%
Non-Specified Industry--diesel oil	21%
Non-Specified Industry--heavy oil	30%

For the steel and cement subsectors, we assumed production in 1996 of 2.5 and 4.5 million tonnes, respectively, or somewhat lower than 1992 production estimates from ROK sources[32]. We assume that fertilizer production decreased to 25 percent of its 1990 value in 1996, which is intended to be roughly consistent with the reported decrease in agricultural fertilizer availability. "Other chemicals" production (including carbide) for 1996 was set 47.5

[34] The coal use intensity for glass production that we used (from Chinese experience) is about 15 percent lower than that reported for Soviet plants in 1965 (V. Kalashnikov, personal communication, 9/97).

percent of 1990 levels. Production in most other industrial subsectors is assumed to be 30 percent of the 1990 value in 1996, consistent with anecdotal estimates of utilization of productive capacity standing at 20 to 50 percent due to lack of fuel and spare parts[35]. For all industries, in 1996, we assume that the energy intensity (fuels use per unit output) was 110 percent of 1990, as industrial equipment (including boilers, for example) are generally less efficient when partially or intermittently loaded then when operating at near full capacity.

2.2.3. Transport sector

The transport sector in North Korea is concentrated on the movement of freight, principally by rail. Visitors to the DPRK have noted that there is relatively little vehicle traffic on city streets and roads, and that the main form of personal transport appears to be walking. This is aided by the fact that the apartments in which most urban dwellers live are typically located close to their places of work. Based on these observations, we have assumed 1,440 average passenger kilometers traveled per year in motorized transport by the roughly two-thirds of the population that is "economically active". This translates to about 900 kilometers of travel in cars, trains, and buses per person (all residents) per year, which is greater than the 1990 level of passenger transport in China, but less than that in India (and far less than that in industrialized countries[33]).

We have relatively little direct quantitative information on the DPRK transport sector and its energy requirements, but have attempted to derive estimates for energy use in the five transport subsectors described below.

The *Road* transport subsector is divided into passenger transport and freight transport. For freight transport, we started with a figure of 42 million tonnes for the amount of freight transported by road (Korea Foreign Trade Association, 1993), but had to guess at an average transport distance of 75 kilometers. Another assumption was that 23 percent of the freight transport occurred in diesel trucks, 5 percent (probably mostly in rural locations) in trucks fitted with biomass gasifiers (or biomass-fueled steam engines?), and the rest in gasoline trucks. Although this is just an assumption, it is informed by 1) the fairly large fraction of gasoline in overall petroleum product consumption as reported by Choi[34]; and 2) the probability that a great deal of freight is transported in the ubiquitous locally produced 2.5 tonne (capacity) gasoline trucks that make up the bulk of the military transport fleet (see discussion of this sector below). Energy intensities for freight transport by truck are taken from USSR data (from the 1970s), and inflated by 20 percent to account for what is probably an older, more poorly-maintained vehicle stock in the DPRK.

Our estimate of gasoline used in civilian autos starts with an estimate, obtained by recent visitors to the DPRK, that there are approximately 15,500 civilian autos (including taxis) in Pyongyang, and very few outside the capital city. These autos, which as of 1990 were all imported (Nissan, Volvo, and smaller Mercedes sedans) during the 1970s and 1980s, were assumed to travel an average of 4,000 km per year (very low for an auto in an industrialized

[35] It is certainly possible that even the drastically reduced levels of industrial production that we assume may be greater than actual production. A 1997 analysis by the US Department of Defense reportedly suggests that DPRK industrial production (presumably as of early or mid-1997) was one-tenth of the level of five earlier (Chosun Ilbo, "POSSIBILITY OF COUP IN DPRK: HONG KONG MAGAZINE", 06/19/97).

nation, but possibly still high for DPRK), and were assumed to have an average fuel economy of 11 km/liter (26 miles per gallon).

For other passenger road transport, we assumed that 30 percent of motorized passenger transport is by road[35], and that 35 percent of this (bus) transport is in diesel vehicles. We took energy intensities from 1985 Chinese data, marked up by 20 percent as for freight transport.

Rail transport in North Korea is fueled by diesel oil and by electricity. An ongoing program of electrifying the DPRK rail system has increased the fraction of freight hauled by electric engines. We assumed this fraction to be 87.5 percent[36]. For freight transport, we began with an estimate of 169 million tonnes of freight carried by rail[37], but were forced again to make a guess (300 km for electric rail, 250 km for diesel rail) as to the average distance of freight transport. We again used marked-up USSR energy intensities for both diesel and electrically-powered freight locomotives (see the "Transport" section of Attachment 1 for specific values and sources).

We assumed that practically no passenger transport is by diesel rail, as railways between most cities are reportedly electrified. The residual 70 percent of passenger transport not provided in road vehicles was assumed to take place in trains, at an efficiency of 13.2 kg coal equivalent per thousand passenger kilometers. The latter is an average 1989 efficiency for US commute-time train transit[38]. While trains in the DPRK are probably less efficient than US trains, their load factors are probably significantly higher.

Our estimate of oil use in transport of freight by *Water* in the DPRK (excluding international shipping) started with an estimate of 18 million tonnes of freight transported[39], and assumed an average transport distance of 200 kilometers. A Chinese energy intensity of 9.9 kg coal equivalent per thousand tonne-kilometers was used[36], and is in the range of energy intensity values for Soviet maritime freight transports, but it may still be too low for the DPRK situation.

The civilian *Air transport* subsector in the DPRK is quite limited. We assumed that the non-jet-engined planes among the 24 total aircraft that reportedly made up the 1990 North Korean civilian fleet would be used an average of 300 hours per year, and that the planes themselves are mostly AN-24 propeller planes (a Soviet design from about 1960), with similar fuel consumption to that which we calculated for AN-24s in military use in the DPRK. The DPRK reportedly purchased three Tupolev Tu-154 jets (similar in size to the Boeing 727) between 1976 and 1978[40], which we assume were used about 750 hours per year. For both the jets and non-jets, the estimates of operating hours that we used are probably more likely to be high than low, given the age of the airline fleet and probable difficulties in obtaining spare parts and aviation fuel. We assumed that the few (4 or 5) international airlines that fly into and out of the DPRK provide all of their own fuel. Thus, the DPRK makes no contribution to international aviation bunkers.

A final category of *Non-specified transport* was added to account for electricity and petroleum product use not included in the categories above. Pipeline transport of oil is one

[36] In comparing this value with the energy intensities we estimate for DPRK military ships, this intensity seems quite low, perhaps by an order of magnitude or more. The low value of the Chinese shipping energy intensity may be due to the much larger ships that are probably used to transport freight in China.

possible use of fuels in this group. We have used placeholder values of 1.8 million and 1 million GJ of petroleum products and electricity, respectively, in this category.

Our estimates of energy use in the transport sector currently includes no coal consumption, although coal may be used as a fuel on some isolated railways or in older ships. As noted above, we have assumed, based on anecdotal reports that trucks fueled with biomass in some form (possibly charcoal) are in use in the DPRK, possibly remnants from the Japanese occupation of Korea during WWII[41]. We assume that these vehicles convert biomass (or biomass charcoal) to producer gas for use in internal combustion engines, although it is possible that some vehicles are steam-driven. We assume that the overall efficiency of biomass-fueled trucks are about 50 percent of the efficiency of their gasoline-driven counterparts.

2.2.4. Transport sector activity changes for 1996

Transport-sector calculations and data that we used to produce our estimates of energy use in the transport sector in 1990 and beyond are presented in Attachment 1. Key assumptions for 1996 are as follows:

- Road Freight—down to 30 percent of 1990 value in 1996, roughly following the decrease in industrial and food output. Use of biomass-fueled trucks increases to move 8 percent of road freight in 1996, up from an assumed 5 percent in 1990. Energy intensities for all gasoline- and diesel-fueled trucks, buses and cars were assumed to be 5 percent higher than in 1990, reflecting poorer fuel economy caused by poorer maintenance (due to lack of parts and lubricants, for example) and a generally aging stock of vehicles.

- Rail, Water Freight—down to 40 and 45 percent (respectively) of 1990 values in 1996.

- Road, Rail Passenger (except civilian auto)—down to 45 percent (54 percent for travel in gasoline buses) of 1990 value per capita in 1996 reflecting a shortage of transport facilities and general “belt-tightening”).

- Civilian Auto passenger kilometers traveled—100 percent of 1990 value in 1996, reflecting an observed continued presence of autos in and around Pyongyang (if not in other areas), as well as reports of (used) vehicle imports from Japan and elsewhere during the 1990s.

- Air transport—down to 80 percent of 1990 value in 1996, with the ratio of fuel consumed in propeller and jet aircraft remaining the same as in 1990.

2.2.5. The residential sector in 1990

Our estimate of energy use in the residential sector begins with the assumption that 60 percent of the approximately 21 million people in the DPRK as of 1990 (excluding the 1.2 million persons in active units of the military) lived in urban areas[42], and that the number of persons per household in both urban and rural households was 4.65[37].

---

[37] This figure is an extrapolation from a single area (the Ongjin area) in southern DPRK (Document in authors' files [FC1]). Although it may not be an accurate weighted average figure for the country as a whole, it is probably fairly close.

For the *Urban* subsector, we assumed, based on the observations of recent visitors to the DPRK, that the average urban household lives in a multi-story building in an apartment of approximately 50 square meters[38]. We further assumed that essentially all of these buildings are centrally heated with coal-fired boilers, although some doubtless take advantage of district heat from power plants and industrial cogeneration. We applied an average figure of 30 kg coal equivalent/m^2 from Chinese data to derive an average household use of 1.8 tonnes of coal per year, or about 44 GJ/household-yr. We further assumed an average electricity use of 770 kWh per household (HH)-year. This is about 2.4 times the average household use of electricity in South Korea in 1975[43], but is roughly consistent with a household using several electric lights, a small refrigerator (if used), a few small appliances, and a household's share of common electricity use (pumps, lighting) in common areas of multi-family buildings.

For urban sector cooking, we assumed that petroleum-based cooking fuels (liquefied petroleum gas, or LPG, and kerosene) are used exclusively in Pyongyang, but are not used extensively elsewhere[44]. Usage of these fuels per household was assumed to be 9.6 GJ/yr, approximately half the energy used reportedly used in wood-fueled stoves in rural households in the Kumgang area. We also assumed, as a placeholder estimate, that 10 percent of urban households used charcoal for cooking at a rate of 440 kg/HH-yr. This assumption produces a charcoal demand consistent with the charcoal production we estimate (see section 3.3). All other urban cooking is assumed to be provided by coal or electricity, with cooking use of those fuels subsumed in the overall coal and electricity use figures cited earlier.

For *Urban* households, we reviewed estimates of household fuel use provided by DPRK officials for three areas of the country. Based on these data, which may or may not prove representative for the country as a whole, and on other anecdotal information, we estimated that 26 percent of rural households use coal for heating and cooking, 5 percent use LPG for cooking (a guess on our part), and that the rest use wood or biomass fuels. These assumptions, and the fuel use rates for each fuel, are detailed in the "Residential" pages of Attachment 1 to this report. Electricity use in rural households was assumed to be less, on average, than in urban households, namely 512 kWh per HH-year.

2.2.6. Residential sector changes by 1996

In the residential sector, we assumed the following changes from 1990 conditions:

- Population decline by 0.14 percent/yr through 2000[39].

---

[38] This size dwelling would be roughly consistent with conditions in parts of China (Liu, F. (1993), Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350), the Former Soviet Union, and Eastern Europe.

[39] The US Central Intelligence Agency ("Korea, North", CIA Factbook, 2001 (World Wide Web Version), USCIA, Washington, D.C., USA, 2001, http://www.odci.gov/cia/publications/factbook/geos/kn.html) lists a 2001 estimated growth rate of 1.22 %/yr and a total population of just under 22 million. The USDOE Energy Information Administration lists a year 2000 population of 21.7 million in its North Korea Country Analysis Brief (www.eia.doe.gov/emeu/cabs/nkorea.html, visited 5/2002). A file of "DPRK Energy Data" provided to Nautilus by the Korea Energy Economics Institute (KEEI, 2002) suggests a year-2000 population of 22.175 million and a growth rate of 0.4 percent annually (with the growth rate decreasing substantially between 1990 and 2000), but uses a year-2000 base population of 20.221 million for the DPRK. While recognizing the extreme difficulty in estimating DPRK population, we continue to assume that year 1990 population was 22 million (as official estimates suggest) and adopt the figure provided by USDOE EIA as the year 2000 population. This suggests a modest decrease in population over the decade which is certainly consistent with food shortages and anecdotal but fairly widespread evidence of lack of proper food rations, as well as medical care, for the DPRK populace.

- The Rural/Urban split remains 40/60 through 2000. We have heard unsubstantiated reports of involuntary urban-to-rural migration, plus reports of residents of northern cities relocating to the countryside where food can more easily be foraged, but we assume for the sake of preparing this estimate that these movements are balanced by rural to urban migration or other demographic shifts.

- Through a combination of austerity and fuel unavailability, that all residential end-uses of coal and urban use of electricity decline to 60 percent of 1990 levels in 1996, with rural electricity use declining to 45 percent of 1990 levels (due to relatively lower availability of electricity in rural areas). Rural biomass use per household is assumed to increase somewhat to offset reduced availability of coal, use of charcoal declines to 75 percent of 1990 levels, and the use of kerosene and LPG in urban and rural homes decrease to 30 and 25 percent, respectively, of their 1990 levels as a result (primarily) of reduced fuel availability[40].

2.2.7. The agricultural and fisheries sectors in 1990

To estimate fuel use in the agricultural sector, we started with the area of field crops grown in the DPRK, approximately 1.7 million hectares[45]. We have divided energy use in the agricultural sector into two components, accounting separately for the fuel used in *Field Machinery*, and that used for *Processing of crops and other applications*.

To estimate the petroleum product consumption in field machinery, we applied a Chinese figure of 41 liters of diesel oil per hectare (ha) farmed[46] to the total DPRK field crop area. By way of comparison, this equates to approximately 6 hours of tractor use per hectare per year if one assumes 1) an average fuel consumption rate of 195 grams per horsepower hour[47]; and 2) a 28-hp tractor, the size that is apparently common in DPRK. If tractors are typically used at less than full power, this hours-per-hectare figure would increase. Official DPRK sources suggest that there are seven to eight tractors per 100 hectares of field crop, which would imply on the order of 10 to 20 days of tractor operation per tractor per year. This level of tractor use seems low, but is not entirely implausible given A) the fairly narrow time windows that Korean weather provide for planting and harvesting crops; B) the large amount of hand labor used in North Korean agriculture; and C) the probable scarcity of fuel and spare parts for tractors in DPRK.

Electricity use in field machinery was estimated using a Chinese value of 126 kWh/ha[48]. Most electricity use would probably be for water pumping.

Chinese energy intensities were also used to estimate the coal and petroleum products used in crop processing and other applications. In this case, we estimated intensities by dividing the figures for consumption of coal and electricity in Chinese agriculture (1987 values) by the total area of rice crop cultivated, then applied the resulting coefficients to the area of rice crop (650,000 ha[49]) cultivated in North Korea. This procedure, of course, yields intensity figures that are approximations at best; the ratio of rice hectarage to area of all crops will be somewhat (though probably not vastly) different in China than in the DPRK, as will agricultural practices and agricultural yields, both of which would affect the energy used in processing crops.

---

[40] We assume that availability of LPG and kerosene for cooking would be even more limited in rural areas than in urban areas, hence the greater percentage decline for rural households. Based on our experience, however, there may be a countervailing effect of increased use of kerosene (and diesel) for lighting as electricity has become less available in the evening hours.

Lastly, we summed figures provided by DPRK officials for straw and bran used as fuel in agricultural operations. This sum provided an initial estimate of the biomass fuel used by the sector. Some wood is probably used in the sector as well, but we have no quantitative data to describe this use.

Very little data are available to describe energy use in the fisheries sector of DPRK. The approach we used was to start with the tonnage of *larger fishing vessels* (700,000 tonnes[50]), to guess at the average annual usage of the fishing fleet, and to apply a Chinese coefficient for energy use intensity of ships, expressed in energy per thousand gross tonne-miles. We assumed that 75 percent of the DPRK fishing fleet was in service, and that those ships spent an average of 200 days at sea, underway (at an average of 10 km/hr) 12 hours per day. Our best guess is that this estimate for the activity of the North Korean fishing fleet is high, if anything, but the Chinese energy intensity is probably a low value for the DPRK.

For other uses of energy in the fisheries sector, including petroleum used by smaller fishing collectives and in fish processing, and electricity use in processing operations, we have used only placeholder estimates. It is possible that some coal, or even wood, is used in ships and/or in the processing of fisheries products, but we have thus far assumed that none is.

2.2.8. Changes in the agricultural and fisheries sectors as of 1996

We assume no significant change in the area cropped between 1990 and 1996, but that the electricity use in both field operations and processing of crop decreased to 90 percent of its 1990 value by 1996 as a result of decreased agricultural output and flood damage, while oil products use (diesel) decreased to 30 percent of the 1990 value by 1996, consistent with observations of greatly reduced farm mechanization due to fuel shortages over the last several years. In the fisheries sector, we assume that 1996 fishing effort (fuels use in fishing and the processing of fisheries products) was approximately 50 percent of 1990 effort, consistent with reports of a recent sizable reduction in marine products output[41].

2.2.9. Public and Commercial sectors

As in the fisheries sector, we have essentially no direct data on the use of fuels in public and commercial buildings in DPRK. To provide a "ballpark" estimate of these quantities, we started with our estimate of urban residential floor space, and applied the ratio of residential urban floor space to public and commercial floor space (approximately 0.3) that prevailed in the "heating zone" of China as of 1989[51]. We then applied coal use intensities (from the same source) to this total. To estimate electricity use, we derived an electricity use intensity of 27.5 kWh/m^2 from Chinese data, and applied it to our public/commercial floor space estimate. In order to bring the sum of electricity demand in the agricultural, public/commercial, and military sectors up toward (but not quite to) the approximately 25 percent share of total electricity demand that these sectors reportedly account for, we included an additional placeholder value of 7 million GJ/yr for other uses of electricity in the public/commercial sector. In the future we hope to improve our estimate of energy use in the public and commercial sector by collecting and applying intensity figures representative of Soviet-style construction.

---

[41] Noland (1996) quotes Y.S. Lee (1995) as reporting a reduction in marine products output between 1989 and 1993.

2.2.10. Commercial/Public/Institutional sector changes by 1996

For all activities in this sector, we assume that total floor space per unit residential floor space to remained constant at 1990 levels through 1996, but that coal consumption per unit floor space decreased somewhat to 90 percent of 1996 levels, and electricity use per unit floor space (and for other sectoral electricity use) declined to 60 percent of 1996 levels, similar to the decline in urban residential electricity use. At these levels of 1996 energy use, the commercial/public/institutional sectors are assumed to have fared better than the industrial or residential sectors, reflecting a rough balance of slowly declining "official" activities in the sector with increasing "private" commercial activities.

2.2.11. The military sector in 1990

Although we have thus far been able to obtain essentially no direct data on energy use in the military sector in the DPRK, the DPRK military is monitored closely by the military and intelligence community in the United States and elsewhere. For our study, this attention has meant that there are reasonably good data on the stocks of energy-using equipment in the DPRK military. These data on stocks can be used as the basis for estimates of fuels consumption. Our approach to estimating fuel use in the DPRK armed forces has been to use these stock figures together with data and estimates of vehicle/aircraft/vessel fuel capacities and estimates of the amount of "practice time" that each piece of equipment might receive in a year. Of these three types of information, our estimate of equipment use are by far the most speculative. The methods and data used to prepare our estimates of fuel use by the DPRK military sector are presented in Attachment 2, and are summarized (and augmented) in the "Military" section of Attachment 1. In addition, the methods and key assumptions that we used in preparing estimates for the different military subsectors are summarized below.

In order to estimate the energy used by the DPRK *Ground Forces*, we started with estimates of the total number of mobile equipment and vehicles in seven classes:

- Tanks
- Amphibious Vehicles (used for fording rivers and lakes), or operating in wet terrain)
- Armored fighting vehicles
- Truck- and Tank-mounted artillery and missiles
- Jeeps and motorcycles
- 2.5 tonne trucks
- Other trucks and utility equipment.

Using information on the number of the different types of regiments and other units in the DPRK Army[52], and on the equipment stocks in each type of unit[53], we estimated the personnel and equipment totals in the DPRK Army. This exercise yielded a personnel total somewhat lower (936,000 versus 1.066 million) than the total reported personnel active in the Army, so we multiplied the resulting equipment totals by 1.14 to "true-up" to the total reported force strength. Next we used data from two US sources[54] that described the various equipment types (size, range, fuel capacity, weight, engine power) to estimate the fuel consumption per kilometer of vehicle travel. We assumed average speeds during maneuvers ranging from 15 to 30 kilometers per hour, and assumed that the vehicles would be active during maneuvers about 50 percent of the time (except for engineering utility vehicles, which were assumed to be active 25 percent of the time). We further assumed that 20 percent of the stock of all types of vehicles and equipment are unusable (due to lack of fuel or spare parts, or just age and decay) at any given time, and that the Army conducts maneuvers approximately 1,000 hours per year. Interestingly, a single type of vehicle--the DPRK's 2 1/2 tonne trucks--dominates both the numbers of vehicles in the DPRK Ground Forces (over 75 percent) and our estimate of fuel used by those forces (two-thirds).

We used our estimates of fuel used by light vehicles, trucks, and utility vehicles in the ground forces to estimate the amount of fuel used by support vehicles in the DPRK Air Force and Navy. We did this by applying simple ratios of the personnel in each branch to the Army fuel use total.

For *Aircraft* in the DPRK Air Force, we used estimates of each class of aircraft (supplied in U.S. Defense Intelligence Agency, 1990) and information on the early-1980s stocks of particular aircraft[55] to estimate the current stocks by model of plane (or helicopter). Most of the DPRK's aircraft are antiquated, with many models dating from the 1960s or before. Of the approximately 1,400 aircraft in the DPRK inventory, approximately 750 are fighters, 80 are bombers, 300 are transport aircraft (90 percent of which are smaller single-engine Russian AN-2 biplanes), and the remainder are helicopters.

Information on aircraft range, size, and fuel capacity was gleaned from the US documents mentioned above, from Jane's All the World's Aircraft[56], and from other[57]. These data were used to estimate the "fuel economy" of the planes and helicopters in the DPRK stock. Based on the assumption that these aircraft receive minimal use--due to their typically advanced age, scarcity of fuel and parts, and the DPRK's typically ground-oriented military doctrine--we assumed fairly minimal annual operating hours of:

- Fighters and Bombers: 24 hours per year
- Transport Planes: 50 hours per year
- Military Helicopters: 32 hours per year.

It is quite possible that some aircraft receive substantially more use than we have assumed, but it is more likely that a large number of aircraft are entirely or effectively in "mothballs" (long-term storage) and receive little or no use. For most aircraft, we assumed that their average airspeed while on training or practice missions is about 80 percent of their reported maximum speed.

Our estimates of fuel use in *Naval* vessels used a similar approach: figures on current total numbers of ships by class in the DPRK Navy were combined with an older[58] inventory of numbers of ships by model to yield estimates of the current number of ships by model and type of ship (including submarines). The DPRK's forces include few ships of any size (by naval standards), consisting mostly of smaller (40- to 400-ton displacement) missile attack boats (40) and patrol craft (over 400), with a number of amphibious craft designed to land troops on beachheads (about 200) and 24 diesel-electric submarines.

We then compiled information on the engine power for each model in this inventory of ships, and used a benchmark figure of 0.38 lb of diesel fuel per horsepower (hp)-hr of operation[42][59], plus an assumption that at cruising speed, naval ships operate at approximately half-throttle (that is, they are using half of the total horsepower available). For submarines, we used a figure of 0.50 lb of diesel per hp-hr[60]. These data were used to estimate the fuel consumption for each vessel per hour of operation.

We assumed, based primarily on conjecture, that amphibious naval vehicles would be in operation only 50 hours per year, that submarines would operate 100 hours per year, and that all other vessels would operate 800 hours per year. The reasons for assuming these low operating levels (the US Naval fleet reportedly has had an operating tempo upwards of 60 percent, or over 5000 hours per year) are the same as those cited above for the low number of operating hours per aircraft. These operating assumptions were multiplied by the per-unit fuel consumption figures and the number of ships of each type and summed to yield overall fuel consumption by the Navy.

In an additional exercise, we estimated the amount of fuel used in *Manufacturing Military Equipment*. This calculation was done by estimating the total weight of iron and steel in the Army and Navy equipment inventories (aircraft were assumed to be all imported), applying estimates of the average of lifetimes of each equipment type (assumed to be 20 years for large Ground Force equipment, 10 years for small armaments, and 30 years for ships and boats), and using these figures to derive an average amount of iron and steel needed per year in military manufacturing. A Chinese figure of 250 kg coal equivalent per tonne of steel[61], multiplied by an efficiency inflator of 1.1, was assumed to be required for each of the approximately two meltings required to fabricate military equipment[62]. It was further assumed that the fuel (assumed to be coal) used in melting iron and steel for military goods represents roughly 60 percent of the total coal needed for military manufacturing. An estimate of the electricity requirements by this sector was prepared by applying the ratio of electricity to coal consumption estimated for the civilian iron and steel industrial subsector to the coal use estimate for military manufacturing.

Armed forces of 1.2 million people do not exist without a substantial stock of military buildings. Sadly, as in other sectors, we currently have no information on energy use in these structures. To compile estimates of fuel use in military buildings, we have assumed that there are 20 million square meters of floor space in such buildings (about 17 square meters per active member of the armed forces), and that they are heated with the same type of coal-fired equipment (and at the same efficiency) used for residential and public/commercial buildings. Electricity consumption per square meter in these buildings was assumed to be twice that in civilian public and commercial building (55 kWh/m^2-yr).

We have included a placeholder value of an additional 5 million GJ to account for other uses of electricity in the military. End-uses covered by this assumed allotment as of 1990 could include fixed radar sites and the DPRK's nuclear research program (nominally a civilian operation), which we estimate may have an electricity demand of approximately 5 MW net of electricity production by the DPRK's 25 MW thermal (5 MW electric) research reactor (prior to its shut-down as part of the Agreed Framework). An additional 20 million GJ placeholder allotment was assumed for other uses of coal in the military, along with an additional 100,000 GJ for other uses of petroleum products.

[42] Although this value is derived from a reference that dates back to WWII, it is apparently not unreasonable. Conversations with a US dealer of large marine engines indicates that even the best current diesels are not vastly more efficient (0.32 to 0.33 lb/hp-hr), and that the value we are using would be justified (perhaps even low) for the older (1960s and 1970s) engines that likely make up the bulk of the DPRK fleet.

2.2.12. Changes in military fuel use by 1996

Our assumptions and calculations for fuel use in the DPRK military are presented on Attachments 1 and in Attachment 2. We assume that there has been a 13 percent decline in ground forces active hours (that is, exercises in which fuel-using vehicles and armaments are actually in use) from 1990 to 1996, a 16 to 25 percent decline in aircraft use[43], and a 25 percent decline in use of most naval vessels. Force sizes were assumed, based on the documents available, to have changed only modestly, with the notable exception being the addition of amphibious hovercraft. Military manufacturing was assumed to decrease to 80 percent of 1990 levels by 1996. No changes were assumed in energy use by military buildings with the notable exception that electricity use for military activities was assumed to decline to 50 percent of the 1990 level. This decline in military electricity use was assumed to be partially the result of changes in the DPRK's nuclear program under the terms of the Agreed Framework[44].

2.2.13. Non-Specified/Other sectors

This category was included to help balance supply and demand if sufficient demand could not be accounted for in the sectors described above. At present the only entry here for 1990 is a placeholder value of 5.7 million GJ of petroleum products consumption, of which 2 million GJ is diesel oil, and the rest kerosene. No non-specified sector energy uses were included in the 1996 energy balance.

2.2.14. Non-energy use

This balance row currently includes wood fuel used as a feedstock for commercial wood (such as lumber) production, and coal used as a feedstock for the fertilizer industry (for ammonia production—see description in the Industrial Sector discussion above). In addition, non-energy use includes petroleum products such as lubricants, bitumen for asphalt, waxes, and petroleum coke. We assume that coal used as a fertilizer feedstock was used at 25 percent of its 1990 level in 1996, that non-energy petroleum products use declined to 30 percent of 1990 levels (consistent with the overall decline in industrial production), and that biomass used as "roundwood" (lumber feedstock) was at 60 percent of 1990 levels by 1996.

2.3. Summary of information on energy supply in the DPRK as of 1990 and 1996

2.3.1. Energy resources

The major primary energy resources used in North Korea are as follow:

- *Coal*, almost all of which is domestically produced. The types of coal mined in DPRK are anthracite and brown coals.

[43] The decline in aircraft use that we assume can be thought of as consistent with a reduction in the supply of spare parts for the DPRK's (mostly) vintage Soviet-type aircraft, as well as reduced availability of fuels.

[44] As noted by Noland (1996), our estimate of fuel use by the DPRK military is rather narrowly focused on fuel used by military equipment, in manufacturing of particular pieces of military equipment, and use of fuels in military buildings. In fact, the DPRK armed forces are reported to control a large fraction of the DPRK economy, and are reportedly involved in a number of enterprises outside of those we have modeled. For these enterprises, however, separating military from civilian activities is probably, at best, very difficult, if not impossible. In any case, the energy associated with these activities owned and operated by the DPRK military in what would be designated in most countries as "civilian" sectors is already included in our energy accounting for the DPRK's national energy balance and is not "missing."

- *Wood and Biomass*, including fuelwood and commercial wood harvested from the DPRK's extensive but degraded forest area, and crop residue biomass.
- *Petroleum*, including imported crude oil and a smaller amount of imported refined petroleum products.
- *Hydroelectric power* from a number of hydroelectric plants (see Section 2.2).

2.3.2. Coal resources in 1990 and 1996

Coal is produced in a number of areas of North Korea. The major coal type mined is anthracite coal, a hard coal that is typically high in carbon and is actually relatively rare world-wide (though common in Korea and adjacent areas of China). Second in importance is much lower quality brown or lignite coal. The DPRK's reserves of coal are significant, sufficient for on the order of 1,000 years at current consumption levels, but the quality of the coal is uneven. The heat contents of coals mined in one major district alone (the Anju district on the west side of the DPRK) vary from 1,000 to 6,000 kcal/kg[45], with ash contents from 12 up to 65 percent. Untreated coals of this quality can be expected to have a low efficiency of combustion, and the large volumes of bottom and fly ash generated when these coals are burned create a disposal problem[b].

Approximately one-half of the coal reserves in the important Anju mining area (located northwest of Pyongyang) are located under the seabed. The DPRK currently lacks the technology to effectively and safely extract this coal, which includes some of the higher-quality coal in the area. In mines in the Anju district that are in areas close to the sea, it is reportedly already necessary for miners to pump six tonnes of sea-water per tonne of coal mined, due to saltwater intrusion into the low-lying coal seams.

Estimates of the amount of coal mined in DPRK vary quite widely, even for a single year, depending on the source of the information. Official estimates are as high as 85 million tonnes of coal (for 1989), while estimates by the National Unification Board (NUB[63]) estimate that the total for 1990 was only 33.2 million tonnes. Further confounding the evaluation of these estimates is the issue of energy contents. Official DPRK figure place the average (apparently) value for coal energy content at 4500 kcal/kg, while NUB apparently assumes an average energy content that is on the order of that used for high-quality anthracite coal[64, 47].

We have assumed, in preparing our estimate, that the production of coal in 1990 was 70 million tonnes, of which 49 million tonnes was anthracite coal, and 21 million tonnes was brown coal[65]. We have taken the figure of 4500 kcal/kg as a weighted average energy content for this coal. Our guess, based on the documents we have reviewed in compiling this report, is that both of these estimates are on the high side.

[45] "Standard" bituminous coal is defined as 29.3 GJ/tonne, or about 7000 kcal/kg, so 6000 kcal/kg is coal of relatively high energy content, while coal of 1000 kcal per kg would be considered of quite poor quality.

[46] Combustion efficiencies decline in part because a large volume of inert material (ash) must be heated up by the burning coal. “Fly ash” denotes that fraction of coal ash that leaves the boiler with the hot exhaust gases and is trapped by ash collection devices or emitted to the atmosphere. “Bottom ash” is that fraction of the inert material in the coal that remains in the bottom of the boiler after the coal is combusted.

[47] It is possible, even, that the NUB estimate is expressed in tonnes of oil equivalent, which would put it even closer, in energy terms, to the official figure (Y.S. Jang, personal communication, 1995).

Imports and exports of coal and coke to and from the DPRK are of modest scale. The DPRK imported about 209,000 tonnes of coke in 1990 (probably from the Former Soviet Union, and 2.38 million tonnes of bituminous coal from China[66]. The DPRK also exported 1.17 million tonnes of anthracite to China[67], so DPRK was a net importer of coal and coke in 1990, but imports comprised only a few percent of the total coal supply. It is likely that imported coal was used primarily for industrial processes such as metallurgy. We assumed that coke imports to the DPRK stood at 36 percent of their 1990 levels by 1996, and that coal imports (assumed to be from China) remained at 1993 levels in 1996. DPRK coal exports were assumed to remain at the same level as 1993 coal exports from the DPRK to China.

2.3.3. Petroleum

There are reportedly oil and gas reserves in offshore areas of North Korea[48], but the country lacks the technologies to effectively explore and develop these resources, and has yet to secure an international partner to aid in such an effort. At present, all of the petroleum products used in DPRK are therefore derived either from imported crude oil refined in DPRK, or from imported refined products. Crude oil imports as of 1990 came from four main sources:

- *Iran*, principally in trade for North Korean armaments;
- *China*, in trade for various goods and for hard currency;
- *The Former Soviet Union*, previously on soft terms but more recently on a much more strict hard-currency basis[49]; and
- *The open market*, for example, through Hong Kong.

The Korean Foreign Trade Association[68] lists total crude oil imports of 2.43 Mte (million tonnes) from the first three sources, while Choi[69] cites a total of 2.8 Mte crude oil imports from all sources. We have used the latter figure in preparing the 1990 energy balance.

In addition to refining these crude oils in its own refineries (see below), the DPRK also apparently purchased (as of 1990) some refined products on the open market. These products, principally diesel fuel, heavy oil, gasoline, and kerosene (in that order of importance) sum to a total of approximately 640,000 tonnes of oil equivalent[70].

As noted above, in the late 1980s and early 1990s, the DPRK was receiving substantial supplies of crude oil from China, Russia, and the Middle East (notably Iran and Libya). Since then, supplies from Russia have reportedly ceased, and shipments from the Middle East have virtually stopped as well. Data from Choi[71] suggest that crude oil imports declined by 23 percent between 1990 and 1991 alone. In 1996, the only crude oil reported to be entering the DPRK has come via pipeline from China. Chinese customs statistics[72] for the first two quarters of 1996 show oil shipments into North Korea at an annualized rate similar to that which has prevailed throughout the 1990s. According to the Korean Energy Economics Institute[73], the DPRK received 80,000 tonnes of crude oil from Libya in 1995, but no shipments have been reported in

[48] DPRK sources place estimates of total oil reserves at 6 to 10 billion tonnes. Although we have been told by independent sources that oil deposits do indeed exist beneath the DPRK and its offshore territory, we have been unable to confirm the extent of those deposits.

[49] Some sources indicate that in recent years exports of oil from the Former Soviet Union to DPRK have fallen to as little as a tenth of the pre-end-of-cold-war level (Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK); and Alexander Karabanov, 1993, personal communication).

1996. Table 2-3 presents crude oil import figures provided by KEEI for 1989 through 1995, plus our extrapolated estimate of crude oil imports for 1996.

Table 2-3: Crude Oil Imports to the DPRK (thousand metric tonnes)

Exporter	1989	1990	1991	1992	1993	1994	1995	1996*
China	1,140	1,160	1,100	1,100	830	1,050	1,020	1,000
Russia	500	410	-	-	-	-	-	-
Libya	-	-	200	200	80	100	80	-
Iran	920	980	220	220	-	210	-	-
Total	2,650	2,450	1,890	1,520	910	1,360	1,100	1,000

Source: KEEI, 1996, personal communication with Mr. Dongseok Roh; based on Chung Woo Jin, The Energy Industry of North Korea, 1996.

* Extrapolation of statistics for first two quarters of 1996. More recent statistics suggest that the total was probably considerably lower.

In addition to the refined products produced at the Chinese-built refinery from Chinese crude oil received in 1996[50], China has provided a small amount of "official" (reported in customs statistics) refined products to the DPRK during 1996. These are assumed to be primarily gasoline, and were estimated (based on figures for the first two quarters of 1996) to total about 25,000 tonnes. This figure is less than one-third of the amount of official exports of refined products from China to the DPRK in 1993[74]. Additional imports of refined products during 1996 reportedly were received from Russia (approximately 100,000 tonnes, assumed to be half gasoline and half diesel oil), plus "one half of the output" of a 750,000 tonne/yr (output capacity) refinery across the Tumen river in China. We assume that this refinery's actual production is no more than 600,000 tonnes per year. We further assume that the output of this small Chinese refinery is of the same composition (by product type) as the Chinese-built refinery in the DPRK, but that fuel exports from the Chinese refinery to the DPRK are weighted slightly toward motor fuels and away from HFO, relative to the refinery's product slate[75]. To reflect KEDO's provision of refined product (HFO) to the DPRK during 1996, we used reported and expected deliveries during the "1996 HFO Year" (11/1/95 to 10/31/96), which total approximately 500,000 tonnes of HFO.

2.3.4. Wood and biomass

Approximately 9 million hectares (ha) of North Korea is covered with forests. Unfortunately, the extensive mining of these forest resources during the decades of Japanese occupation of Korea (ending in World War II), coupled with generalized devastation of the Korean peninsula during the Korean war in the early 1950s, have left the forest stocks of DPRK in generally poor condition. A significant reforestation effort, totaling some 2.5 million hectares of plantations by 1993, is reported to be taking place[76]. A total of 3 million hectares are classified as "productive forests".

---

[50] See "Oil" worksheet of Attachment 1 for an estimate of 1996 refined product output by this refinery.

Various figures have been given for the level of domestic wood production in the DPRK, ranging from about 7[77] to approximately 16 million cubic meters of wood. We have used the higher end of official DPRK estimates[78] that sets wood used for firewood at 8 - 10 million m^3, wood for charcoal production at 0.8 to 1 million m^3, wood for construction at 3 - 5 million m^3, and approximately 500 - 650 thousand m^3 for industrial fuelwood and for paper production[51].

In addition to its domestic production, the DPRK also imports wood from the Russian Far East. Teams of workers from the DPRK are sent to harvest wood in Russia, and the DPRK retains a share of the wood harvested in exchange for the labor (reportedly approximately one third). There appears to be a discrepancy between sources as to the magnitude of these imports, but we have assumed a total of 2.5 million m^3 of roundwood (logs) are imported annually from Russia. Much of this wood is probably used as commercial wood (lumber and other products) with milling wastes used for fuelwood, manufacture of small items, paper-making, and other applications.

We found a limited amount of direct information on the consumption of non-wood biomass for fuel. A document in our files[79] reports that a total of 3.1 million tonnes of crop residue (straw and bran) was used in agriculture in 1990. To this figure we have assumed a total of 11 million additional tonnes of crop residues were used, primarily in the rural sector, in order to provide sufficient biomass supply to meet demand. Although this figure is plausible, given the areas and reported yields of crops in the DPRK, it is probably somewhat high, indicating that our estimate for 1990 wood/biomass fuel demand in the rural residential subsector (see below) is also somewhat on the high side.

The DPRK biomass production potential probably was damaged in some areas by the floods of 1995 and 1996. In addition, increased foraging in response to the food shortages in the DPRK may end up having a long-term detrimental impact on the forests of the DPRK. For 1996, we assume that sufficient domestic wood and biomass resources were available to meet demand, and that wood imports remained at the same level as in 1990, although this assumption has yet to be confirmed.

2.4. Transformation Processes in 1990 and 1996

We have included the following fuel-transforming processes in the estimated DPRK supply-demand balance:

- *Electricity generation*, including thermal power generation fueled with coal and oil products, and hydroelectric generation;
- *Petroleum Refining*;
- *Coal Production and Preparation*; and
- *Charcoal Production* from wood.

Also included in the balance are categories for *Coke Production*, which is not accounted for separately from other coal use at present; *Other Transformation*, for future inclusion of major

[51] When wood volumes are specified, it is important to note whether they are listed as "solid" or "stacked" volumes, as the latter implies a lower density, and thus lower energy content per cubic meter, than the former. The volume estimates that we are using appear to be in solid cubic meters, thus we have assumed a conversion factor of 1.5 cubic meters per tonne in estimating the energy content of these wood resource flows.

transformation processes that we may not have yet taken into account; *Own Use*, for use of fuels during transformation processes; and *Losses*, for losses of fuels between the point at which they are produced and the point at which they are consumed.

2.4.1. Electricity generation in the DPRK, 1990 and 1996

There are reportedly over 500 electricity generation facilities in the DPRK. Of these, however, only 62 major power plants operate as part of the interconnected transmission and distribution grid, with the remaining plants being primarily small, isolated hydroelectric facilities and/or facilities associated with industrial installations. One estimate suggests that 85 percent of total national generation takes place in the 62 major power plants; other, unofficial reports suggest generation at smaller plants is insignificant. The 62 "major" plants reportedly include 42 hydroelectric plants and 20 thermal plants. Of the thermal plants, 18 are reportedly fired primarily with coal[80]. The power generation system in general suffers from a lack of spare parts (particularly for plants built with USSR assistance), as well as a lack of testing equipment for use in maintenance activities.

2.4.1.1. Total electricity generated and losses in 1990

Our estimate of electricity generation starts with the assumption that gross generation in North Korea in 1990 totaled 46 TWh of electricity[81]. This estimate is somewhat closer to official DPRK estimates (60 TWh and higher) and UN estimates (55.5 TWh[82]) than to estimates by ROK sources (27.7 TWh[83]), Russian sources (35 TWh[84]), and more informal estimates of 31-32 TWh[85], but the latter may be a consumption rather than a production figure. To split total generation into thermal and hydroelectric generation, we adopted the official DPRK figure, which indicates that slightly more than half (54 percent) of all electricity generation occurred in thermal plants in 1990[86]. To provide separate estimates of coal-fired and oil-fired electricity generation, we started with an estimate of generation in the DPRK's largest oil-fired plant. We then assumed, based the available partial accountings of the number, type, and size of generating facilities, and on more informal reports, that generation in this plant (the Oung gi plant, associated with the refinery at Sonbong) comprised 100 percent of all oil-fired generation. Subtracting total oil-fired generation from total thermal generation yielded our estimate of total coal-fired generation.

For losses, we used the official estimate that 10 percent of net generation is lost in electricity transmission, and an additional 6 percent in distribution (T&D)[87]. These estimates are in aggregate similar to current Chinese values for such losses, but may be optimistic. Except in the Pyongyang region, the DPRK power grid is dispatched literally by phone, and outages on the grid are frequent. But as records of power consumption at the end-user are apparently not common in DPRK, there is probably limited opportunity to determine the true extent of transmission and distribution losses[52].

[52] Other reports indicate that total electricity losses in the DPRK were on the order of 25 percent of generation in 1990, but the 25 percent figure includes routine and emergency station losses and "own use" as well as T&D losses. Our estimate of 16 percent T&D losses, coupled with our estimates of own use and emergency station losses, yield an overall loss rate that is also in the 25 percent range.

There is a considerable but unknown amount of self-generation of electricity by industry. We do not know whether this generation is accounted for in the total electricity generation estimate that we have used, but since our estimate for total generation is more likely to be high than low, we assume that self-generation has been adequately taken into account. Likewise, there is an unknown but substantial amount of district heating in the DPRK, some of which may use steam generated in fossil-fueled power plants (this in addition to steam provided by the 11,000 small- to mid-sized boilers used in buildings and industries in the DPRK). If district heating from power plants proves extensive, it would likely increase our estimate for coal used in the power sector, but reduce our estimate for coal used in the urban residential and public commercial sectors.

2.4.1.2. Detail of existing thermal generating facilities

Although there are discrepancies between the various estimates of the installed capacity of thermal electricity generating capacity in the DPRK[53], we have assumed that the total installed and potentially usable[54] thermal generating capacity as of 1990 was approximately 3,200 megawatts. Table 2-4 provides our best attempt, compiled from a number of sources, at a plant-by-plant accounting of the capacities and vintages of some of the thermal generating facilities in the DPRK. The total of the listed plants (6 plants, 2,850 MW as of 1990) comes up short of both the 20 thermal facilities reportedly connected to the grid and to the 4,500 MW of capacity that has been reported in official documents to be the overall total. If our 3,200 MW total is correct, this figure means that the additional 14 reportedly grid-connected thermal facilities have an average capacity of about 25 MW each. We assume that there exist additional smaller and/or industry-associated plants that fit this description, but updated or more accurate information on this topic is needed to complete the picture.

Table 2-4: Major Thermal Generating Facilities in the DPRK[55]

#	Name		Capacity (MW)	Fuel	Year Completed
1	Pyongyang		500	Coal	1968
2	Bukchang		1600	Coal	1985
3	Chongjin		150	Coal	1984
4	Chonchonang		200	Coal	1979
5	Oungi		200	Oil	1973
6	Sunchon		200	Coal	1988
7	East Pyongyang		50	Coal	1992
TOTAL OF LISTED PLANTS			**2900**		

[53] 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 6,000 MW of thermal capacity in 1990. We have adopted the United Nations figure as our estimate for 1990.
[54] It has been reported that a large number of the smaller power plants reportedly included in official estimates of overall generation capacity were essentially built as "shams" to satisfy authorities, and are actually never been capable of generating power.
[55] Please see Attachment 1 for a listing of the sources used in developing this table.

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, one is the 200 MW plant at Sonbong (listed as "Oungi" in the table above, and also referred to sometimes as "Oung gi" and "Unggi" by other sources) where many of the KEDO heavy fuel oil (HFO) deliveries have been made.

Since 1990, the only reported major addition to the roster of thermal power plants has been the completion in the early 1990s of the (reportedly) 150 MW East Pyongyang plant. Reports indicate that only 50 MW of the 150 MW plant were actually completed, and only with great difficulty, as Russian assistance was not available at that time to complete the work on the plant that was started in the 1980s in collaboration with the USSR. Although the Korea Energy Economics Institute (KEEI) reports that a new 600 MW plant called Dongpyungyang at Nakrangku, Namposhi was completed in 1996, we do not know if the Dongpyungyang plant is an addition to an existing plant in the Pyongyang area (perhaps East Pyongyang?), or a completely new plant, or whether it has in fact run in 1996—although sources indicate that it hasn't. Given these uncertainties, we have assumed for the purposes of modeling that the total thermal generation capacity in 1996 was the 3,200 MW reported in 1990, plus 50 MW for the addition of the East Pyongyang plant. A number of other thermal generating facilities have been reported to be under construction in the DPRK. A roster of these plants is provided in Table 2-5. We do not know the project status of construction of these facilities. We have been told that, as of 1996, thermal power plant construction had stopped except at the East Pyongyang power plant.

Table 2-5: Thermal (fossil-fueled) Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK[56]

#	Name	Capacity (MW)	Fuel	Year Started	Year Completed
1	Pyunghung(?)	200	Coal		
2	Suncheon(?)	200	Coal		
3	Dongpyungyang	600	Coal		1993 - 1996
4	Kimchaek	150	Coal	1988	
5	Hamhyng central	100	Coal	1994	
6	12wol	150	Coal		1993
7	Haeju	Unknown	Coal	1990	
8	Ahnju	1200	Coal	1989	
9	Hamheung	150	Coal	1989	
TOTAL OF LISTED PLANTS		**2,750**			

In order to calculate the fuel used by thermal power plants, we have assumed that coal-fired plants use heavy fuel oil primarily as a start-up fuel in 1990, with HFO constituting about 2.0 percent of the total heat value of input fuel. Using figures for electricity generation by fuel type derived as indicated above, we then calculated the fuel requirements for thermal electricity

[56] Please see Annex 1 for a listing of the sources used in developing this table. Due to differences in nomenclature and translation between sources, there may be some plants that are actually listed twice on this list.

generation using gross generation efficiencies of 29.5 percent for oil-fired plants[57] and 28 percent for coal-fired plants. The efficiency figure we have assumed coal-fired plants is somewhat lower than the average heat rate (30 percent) reported in the Chongjin plant in the Sonbong area, but are comparable to Chinese electricity generation efficiencies for thermal plants of late-1970s vintage[88, 58].

The "own use" of electricity in oil-fired and coal-fired plants was assumed to be 8 and 9 percent of gross generation, respectively. These own use values are those quoted for the Oungi and Chongjin plants, respectively[89]. For coal-fired plants, we assumed an additional "emergency loss" rate in 1990 of 5 percent (accounted for in the "own use" row), which is a bold extrapolation from experience at the Pyongyang power station[90], and may be indicative of poor operating conditions in all DPRK coal-fired power plants. For 1996, we increased this rate to 7.5% of gross generation.

2.4.1.3. Detail of existing hydroelectric facilities

North Korea is a mountainous country with substantial rainfall. Thus it has fairly extensive total potential for hydroelectric development. The DPRK's ability to mobilize massive work forces 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. Table 2-3 provides a listing of those major hydroelectric facilities about which we have capacity information. The 20 plants on this list built prior to 1990 account for approximately 3,100 of the 4,500 MW of hydroelectric capacity reportedly in service as of 1990, and probably comprise about half (numerically) of the grid-connected hydroelectric plants. Electricity from several plants on this list (Supung, Ounbong, T'aep'enmang, and Weewong) is exported to China. Note that the capacities listed in Table 2-3 exclude the portions of power generated in those four plants that is sent to China. Including that portion of the capacity reportedly under contract to China (700 MW) raises the total 1990 capacity accounted for by the facilities in Table 2-6 to 3,800 MW, almost 85 percent of the total capacity reported.

Many of the smaller hydroelectric facilities in operation in the DPRK, are reportedly of the "run-of-river" type, meaning that relatively little water is impounded behind the dams. Although this would tend to suggest that electric output from the DPRK's hydro plants may be more likely to be subject to the vagaries of the weather—poor rainfall months or years resulting in lower-than average electricity production—than systems with more impoundment-type dams, it has been suggested that the larger plants, including those initially designed and built during the Japanese colonial era, reportedly combine impoundment and run-of-river elements, resulting in relatively high capacity factors[59].

[57] This value is substantially lower than an official (we assume) figure of 35 percent quoted in UNDP (1994) (Studies in Support of Tumen River Area Development Programme, as prepared by KIEP, Seoul, ROK for the UNDP, July, 1994). An efficiency of 35 percent seems too high oil-fired generation in the DPRK, given reports about the condition of the oil-fired plant at Sonbong. The 29.5 percent efficiency we have used is consistent with information we have received about the Sonbong plant's recent operations.

[58] It should be remembered that most of the thermal power plants in the DPRK were built with assistance from the USSR—the example of efficiencies in Chinese plants is used here only as a benchmark.

[59] As an example of the potential of the combined impoundment/run-of-river design to produce power consistently, Prof. Y.S. Jang (personal communication, 1996) reports that the capacity factor of hydroelectric plants in North Korea was over 70 percent during 1943.

Table 2-6: Major Hydroelectric Generating Facilities in the DPRK[60]

#	Name	Capacity (MW)	Year Completed	Year Refurbished
1	Supung	400		
2	Kymgansang cascade	13.5	1930	1958
3	Puren cascade	28.5	1932	
4	Puch'on-gang	260	1932	1956
5	Chanjin-gang	390	1936	1958
6	Hoch'on-gang	394	1942	1958
7	Tonno-gang	90	1959	
8	Kangae	246	1965	
9	Ounbong	200	1970	
10	Sodusu-1	180	1974	
11	Sodusu-2	230	1978	
12	Sodusu-3	45	1982	
13	Taedong-gang	200	1982	
14	Mirim	32	1980	
15	Ponhwa	32	1983	
16	Hwan-gang	20	198?	
17	Tonhwa	20	198?	
18	T'aep'enmang	90	1989	
19	Weewong	200	1989	
20	Nam-gang	200	1994	
21	Dokro river	36		
TOTAL OF LISTED PLANTS		**3,307**		

Table 2-7 presents our summary of hydroelectric plants under construction or planned as of the early 1990s. Although the capacities of these plants—to the extent that they have been assigned an estimated value—add to nearly 3,000 MW, we have little information about how far construction on these projects (if any) has progressed. The only exception is the Kumgang Mountain plant, a first phase of which (reportedly about 125 MW) was opened in 1996. We have been told that, as of 1996, construction on all hydro plants except the Kumgang Mountain plant (which reportedly has political and military importance beyond its role in the power sector) was at a standstill.

Given the location and extent of the flooding in the DPRK during 1995 and 1996, it always seemed probable to us that the DPRK hydroelectric system had sustained significant damage. Until recently, however, all of the reports that we could glean either yielded no information about the impacts of flooding on hydro production, or indicated minor damage to smaller facilities. Recently, however, information from a source that we consider reliable indicates that reservoir siltation and perhaps mechanical damage at major hydroelectric facilities has in fact taken place, to the extent that the effective capacity factor of hydroelectric facilities in 1996 was on the order of 15 percent. We have modeled this reduction in usable hydroelectric capacity by assuming that available hydro capacity at existing facilities falls by about 3250 MW

[60] Please see Annex 1 for a listing of the sources used in developing this table.

from 1990 values by 1996 as a result of flood damage[61] offset slightly by additions to capacity[62]. We have further assumed, based on conversations with those familiar with the situation, that 1996 exports of power to China were reduced to about 28 percent of their 1990 levels as a result of flood damage to the hydroelectric stations on the DPRK/Chinese border.

Table 2-7: Major Hydroelectric Generating Facilities Reported to be Under Construction or "Planned for Construction" in the DPRK [63]

#	Name	Capacity (MW)	Year Started	Year Completed
1	Taechun	750	1983	
2	Kumgang Mountain	800	1985	1996 (1st Phase)
3	Sodusu-4	200	1990	
4	Namkang	Unknown	1983	
5	Youngwon	Unknown	1986	
6	Ehrangcheon	Unknown	1986	
7	Jabgjakang	240		
8	P'och'on	820		
9	Oranch'on	180		
10	Heech'on	Unknown	1989	
11	Kymyan-gang	Unknown		
TOTAL OF LISTED PLANTS		**2,990**		

Our estimate for the supply of hydroelectric power in 1990 starts with the figure of 46 TWhe described above, of which slightly less than half (46 percent) is assumed to be generated in hydro plants[91]. These two figures, taken together, imply an overall capacity factor for hydroelectric facilities of about 54 percent. We counted the hydro input energy to electricity generation assuming an efficiency conversion of 100 percent output electricity to input energy, as is done in United Nations statistics[64]. The "own use" of electricity in hydro plants was assumed to be 0.3 percent of gross generation, which corresponds to ROK conditions in 1970[92], and is also similar to values for Chinese plants.

2.4.1.4. Status of the Transmission and Distribution Network

The unified electrical grid in the DPRK apparently dates back to 1958[93]. The DPRK T&D system must nominally manage a fairly complex grid of 62 power plants, 58 substations,

[61] 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.

[62] KEEI (Korean Energy Economics Institute, 1996; personal communication from Mr. Roh Dongseok, Electricity Policy Division) cites an 800 MW increase in capacity from the newly-opened Kumgang Mountain plant. Earlier ROK estimates had also placed the (expected) capacity of this plant at 800 MW, although its current capacity under the phases now completed and/or taking into account existing reservoir levels is probably in the range of 100 - 150 hundred megawatts. The Kumgang mountain plant was also referred to in announcements in the DPRK press, but without reference to plant capacity.

[63] Please see Annex 1 for a listing of the sources used in developing this table.

[64] Note that the actual conversion efficiency of energy in falling water to electricity in hydro plants is typically less than 100%, on the order of 70 to 90 percent.

and 11 regional transmission and dispatching centers. Our limited information on the DPRK T&D system is presented below.

Main Transmission Lines, Substations, and Dispatching Centers

A general map of the electricity transmission system in the DPRK is provided as Figure 2-1. The main transmission lines in the DPRK are rated at 220 and 110 kV (kilovolts).

The main transmission lines in the DPRK include (but are not limited to) the following:

- A 220 kV line from the Buckchang (also referred to as "Puckchang") thermal power plant to the Vynalon substation
- A 220 kV line from the Vynalon substation to the Chanjin-gang power station
- A 220 kV line from the Buckchang thermal power plant to the Chanjin-gang power station
- A 220 kV line from the Chanjin-gang power station to the Kangae hydro power station via the Taedong-gang hydro power station
- A 220 kV line from the Kangae hydro power station to the Ounbong hydro power station
- A 220 kV line from the Buckchang thermal power plant to a substation located southeast of Pyongyang (probably named "Pyongyang No. 2") via the Songchon substation
- A 220 kV line from a substation located southeast of Pyongyang to the Pyongyang thermal power plant
- A 220 kV line from the "Central center" in Pyongyang to the Chonchonang thermal plant
- A 110 kV line from the Chonchonang thermal plant to the Supung hydro power plant. The Taechon hydro power plant is also connected to this line.
- A 110 kV line from a substation located west and slightly south of Pyongyang (probably named "Pyongyang No. 1") to the Supung hydro power plant via the Sin-Anju substation. The Taechon hydro power plant is also connected to this line.
- A 110 kV line from a substation located west and slightly south of Pyongyang to the "Central Center" in Pyongyang
- A 110 kV line from a substation located southeast of Pyongyang to the "Central Center" in Pyongyang
- A 110 kV line from the Pyongyang thermal power station to the "Central Center" in Pyongyang
- A 110 kV line from the "Central Center" in Pyongyang to the Buckchang thermal power station.
- A 110 kV line from the Pyongyang thermal power station to the substation located west and slightly south of Pyongyang
- A 110 kV line from the Chanjin-gang hydro power station to the Danchon switching station, via another substation or switching station

- A 110 kV line from the Danchon switching station to the Chongjin substation (and Chongjin thermal plant)

In the Tumen River area, the system of 110 and 66 kV transmission lines has been estimated to include[94]:

- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) to the Puryong area and North to the Chinese border at Haeryong
- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) to the Aoji area
- A 110 kV line from the Chongjin substation (and Chongjin thermal plant) along the coast to the Unggi and Sonbong area
- A 66 kV line from the Chinese border at Haeryong further north along the border to Onsong
- A 66 kV line from Onsong to the Hunyung area
- A 66 kV line from the Hunyung area to the Aoji area
- A 66 kV line running east in a loop near the border from the Aoji area through the Unggi and Sonbong area.
- A 66 kV line from the Puryong area to the Musan area.

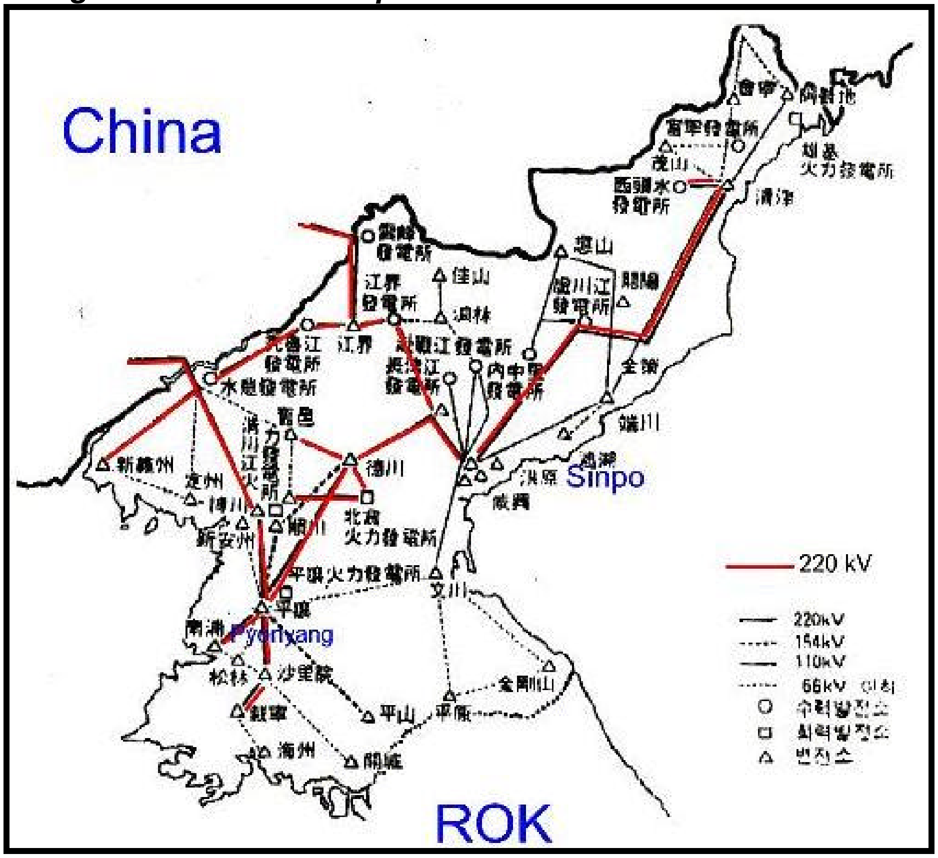
In addition to these lines, there is reportedly a 60 kV line supplying power (possibly from the Supung hydro plant) to a remote area of China. There are certainly other transmission lines in the DPRK, but we do not, at present, have their specifications. In some locations, 66 kV lines (or possibly 60 kV lines—sources differ on the voltage specification) are used for transmission, as well as for bulk distribution. In particular, it is reported that 66 kV line is used in the regions of Kongonwon, Saebyol, and Onsong[95].

In addition to 60 kV distribution lines, 10 kV and 3.3 kV lines are used for bulk distribution of power. Secondary distribution voltages are reportedly 380 and 220 volts[96], although some outlets are supplied at both 110 and 220 volts.

As of early 1992, the DPRK had plans to build 200 km of 220 kV power lines, 60 km of 110 kV lines, and 500 km of 66 kV lines per year through the year 2000[65]. Although we do not know the status of these construction projects, we assume that progress has not achieved targeted levels. Also as of 1992, the DPRK had plans to build a 330 kV transmission system, with implementation to start within 2 years, and also planned, in the long term, to build a 500 kV transmission system. We assume that little progress has been made on either of these higher-voltage systems.

[65] Kilometers of line here probably refers to conductor-kilometers.

Figure 2-1: Overall Map of the DPRK Electric Power Grid



There are reportedly 58 substations on the DPRK grid. We have capacity information about only four of these[66], and names for a number of others. These data are provided in Table 2-8. A substation in the Sonbong area is reportedly rated at 110 kV, and there are (or were to be by 1995) two 110 kV substations and one 220 kV substation in the Chongjin district[97]. The substations in the DPRK are reportedly antiquated—based on obsolete Russian and Chinese technology—and also poorly maintained. Our assumption is that most or all of the substations would need to be replaced, or at least substantially refurbished, to bring the DPRK grid up to modern standards. We do not have a detailed estimate for the costs of updating or replacing existing transmission lines and substations in the DPRK. As a benchmark, however, cost estimates presented in the context of Tumen River area infrastructural development would appear to indicate that a mixture of new 110 and 220 kV transmission lines and substations in the DPRK will cost in the range of $250,000 to $500,000 per conductor-kilometer (most lines will have at least two conductors)[98]. Estimates of transmission lines in South Korea are similar, about $150,000 to $300,000 per conductor-kilometer for 154 kV lines, and $400,000 to $600,000 per conductor-kilometer for 345 kV lines. Costs for substations, again from ROK sources, are about $10 million for 154 kV units, and $36 million for 345 kV substations[67]. Costs for transmission lines vary considerably with the capacity and voltage of the line, the topography to

[66] Capacity is supplied in units of million volt-amps (MVA).

[67] Representative costs for transmission lines and substations supplied by KEPCO (personal communication, 8/14/97). The costs for substations shown are at the low end of the range supplied. Enclosure costs can increase the costs of substations.

be covered, and other variables. Assuming an average transmission line costs cost of $250,000 per conductor kilometer, a total length of (2-conductor) line to be replaced of about 5,000 kilometers (also a very rough estimate), and 58 substations and 11 control centers to be replaced (or refurbished) at a cost of $10 million each yields an extremely rough, order-of-magnitude estimate of about $3 billion for the costs of replacing the entire DPRK electricity grid[68]. Given the rugged topography of the DPRK, costs might be much higher, although the use of existing substation sites and power line right-of-ways (as well as the possibility of using some existing equipment) might be a mitigating factor. Depending on the materials used in the existing substations, there may be environmental issues and costs associated with substation replacement.

Table 2-8: Partial Listing of Substations on the DPRK Electrical Grid[99]

#	Name	Capacity MVA	Units
1	Changjingang	48	1x28, 1x20
2	Chongjin	165	1x100, 1x5, 1x60
3	Pyongyang No. 2	100	2x50
4	Vynalon	200	2x50, 1x100
5	Pyongyang No. 1		
6	Undok		
7	Munsan		
8	Kilju		
9	Hamhung		
10	Songchon		
11	Sepo		
12	Nampo		
13	Kusong		
14	Sinuiju		
15	Pyongsong		
16	Sin-Anju		

The T&D system is supposed to be controlled by the Electric Power Production and Dispatching and Control Centre (EPPDCC) in Pyongyang and by 11 regional dispatching centers. The names of the regional centers are provided in Table 2-9.

[68] Again, it must be stressed that this is the roughest of estimates. It would not surprise us if a more thorough estimate of the costs of replacing/refurbishing the DPRK transmission grid was within the range of $2 to $10 billion, exclusive of any costs for refurbishing the power plants themselves. Also excluded from these estimates are costs of refurbishing distribution systems (if necessary). Simply installing electricity meters on the distribution feeders to the (very roughly) 5 million households and other electricity users in the DPRK alone would likely cost on the order of $0.25 to $1 billion dollars.

Table 2-9: Listing of Regional Control Centers on the DPRK Electrical Grid[100]

#	Name	Location (city)
1	North Kamgyong	Chongzin
2	Ryanggang	Hyesan
3	Chagang	Kanggye
4	South Hamgyong	Hamhung
5	South Pyongan	Pyongsong
6	Kangwon	Wonsan
7	North Hwanghae	Sariwon
8	Nampo	Nampo
9	South Hwanghae	Haeju
10	Kaesong	Kaesong
11	North Pyongan	Siniju

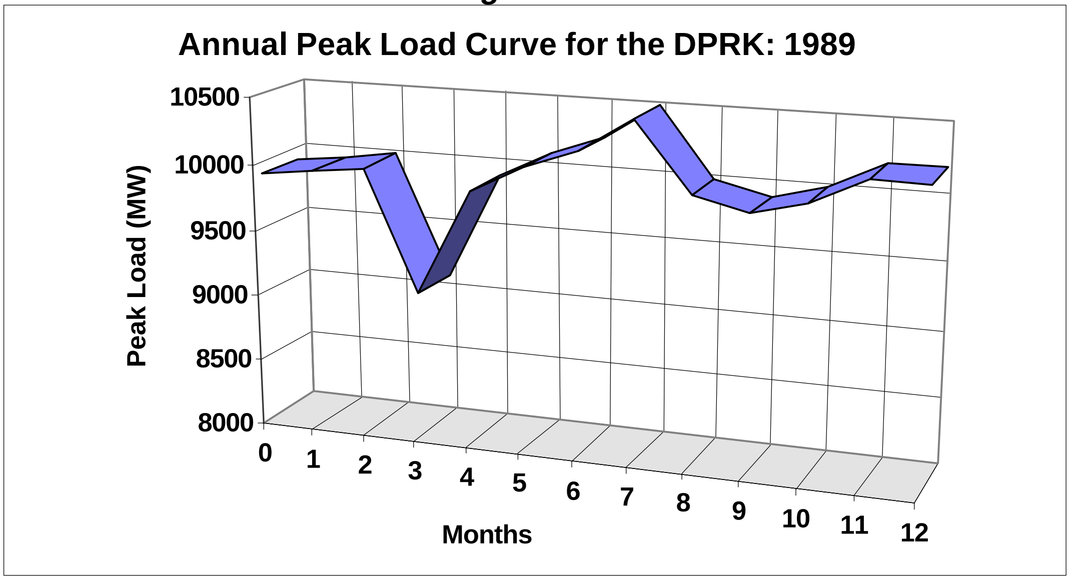
Reported Status of Transmission Network

For losses, we used the official estimate that 10 percent of net generation is lost in electricity transmission, and an additional 6 percent in distribution[101]. These estimates are in aggregate similar to current Chinese values for such losses, and comport with independent reports of loss rates (as noted above), but may still be optimistic for the DPRK. As records of power consumption at the end-user are apparently not common in DPRK, there is probably limited opportunity to determine the true extent of transmission and distribution losses.

As of 1989, load shedding was reportedly frequently practiced, with 1,000 MW shed in the winter season (November/December) and up to 2,000 MW shed in the spring (March/April/May) as water levels in the hydroelectric reservoirs decreased and only minimum hydro power generation was available. It is not clear to us, however, whether load shedding at that time was principally a function of lack of generation resources, of unavailability of generation units, or of defects in the T&D system, or, more likely, was a complex combination of these factors.

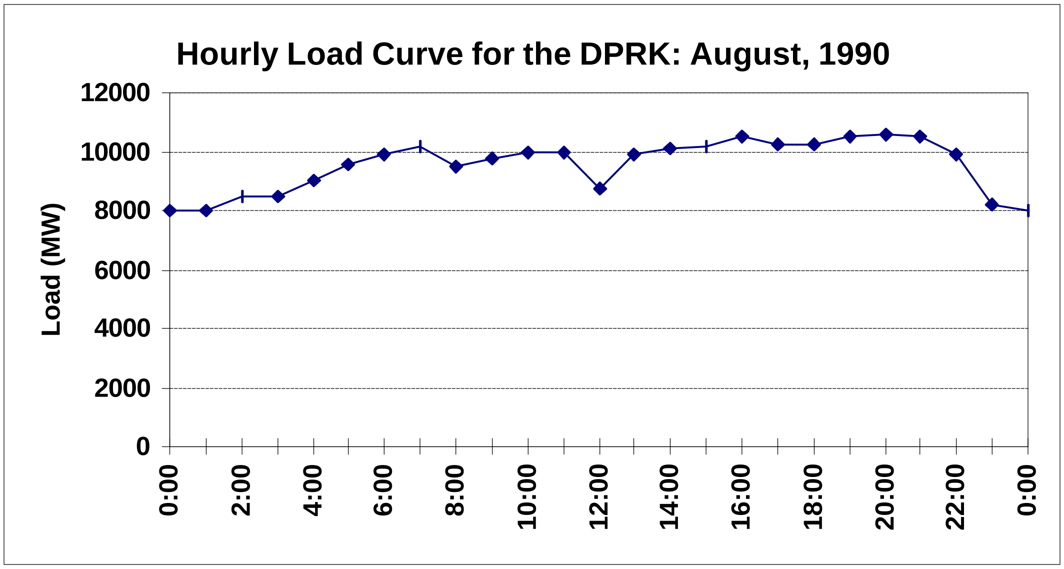
The reported annual variation of peak load for the year 1989 is provided in Figure 2-2. We do not know to what extent the load figures in this graphic may be overstated, or to what extent load shedding, if any, is reflected (either included or excluded) in the curve. The curve show peak power demand in the DPRK to be relatively insensitive to changes in seasons, with demand in July being about 5 percent higher than average, and demand in March being about 10 percent lower. The stability of the peak over the year is not unreasonable, given the extent to which industrial electricity demand is a dominant over demand in the other sectors in the DPRK. 1989 was, however, an unusual year for the DPRK, in that it was the year in which the DPRK hosted a massive international youth festival that likely resulted in at least somewhat atypical load patterns. In addition, it has been reported that schedules in industrial plants in the DPRK at least were (as of 1990) coordinated so as to make maximal use of electricity supplies. It is conceivable that the summer peak has something to do with higher use of fans and some air conditioning in institutional buildings, but this is only speculation on our part. Why demand should be lower in March, we do not know, unless what is being reported in Figure 2-2 is actually peak power supplied, which could be lower in March due to lack of availability of hydroelectric resources.

Figure 2-2:



The variation of peak load over time during a weekday in August, 1990 is provided in Figure 2-3. Peak load appears to exceed baseload by about 30 percent, which is somewhat less than in many countries. Again, the large portion of power demand accounted for by the industrial sector is probably the reason why the ratio of peak power to baseload power is not greater. Based on the load curve shown in Figure 2-3, the load on the DPRK grid peaks broadly in the early evening (about 7 PM to 9 PM), with a minor peak in the morning (about 7 AM). There is a relatively substantial dip in demand at about the noon hour, which could be possibly be explained by industrial facilities shutting down (partially) when workers take their lunch. Some factories, as of the early 1990s, were also known to phase their workdays to allow maximum use of baseload capacity (for example, in Hamhung). There also may well have been unmet demand during peak times during 1990, meaning that the actual peak would have been higher if supplies of electricity had been sufficient.

Figure 2-3:



Dispatching Capabilities and Systems

Connections between the elements of the T&D system were, as of the early 1990s, reportedly operated literally by telephone and telex, without the aid of automation or computer systems. This system results in poor frequency control, poor power factors, and power outages[69]. Outages on the grid are reportedly 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[102]. 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 readout of neither measurements such as voltage, current, active power, frequency, nor status indicators such open/close conditions of circuit breaker 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". (See Section 2.3.5 for information on the status of projects to update the dispatching system.)

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 guide remote operators in restoring the system through the aforementioned system of telephones and telexes, and without access to complete system information on which to base their instructions.

It has been reported that as of 1996, the DPRK grid did not really function as a single unified grid any longer, but as a group of mostly independent regional grids. We do not know what technical or operating problems (among those noted above and below) are central in

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

preventing operation of the unified grid, but identifying and solving those central problems will likely be a requirement if the KEDO reactors are to be used effectively and safely in the DPRK.

Technical Parameters of the T&D System, and Technical Challenges to Integration with Systems in Other Countries

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 (reports as of 1990)[70].

Of the neighboring countries, both China and Russia have electricity systems that operate at 50 Hz, while the grid in the Republic of Korea operates at 60 Hz. This difference means that in order to interconnect the DPRK 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[103]. 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 there is significant capital cost savings.

Although the ROK power grid operates at nominally the same frequency as the DPRK grid[71] we suspect that interconnection of the grids, in their present form, will require some power conditioning at the point of interconnection to assure that the power entering the ROK meets ROK standards for frequency and other attributes. The best way to achieve this outcome is probably to add a station near the DPRK/ROK border that converts the AC (alternating current) power from the DPRK to DC (direct current) power, then back to AC power synchronized with the ROK system for export to the south. 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 one percent. The cost of AC-DC-AC a systems of the size that would be required is on the order of US $125 million per GW of capacity[72], 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 inter-conversion costs suggests (to us) two interesting questions related to the ordering of ROK assistance (if forthcoming) in revamping the DPRK grid:

---

[70] The historically poor control of frequency, and frequent loss of power, on the DPRK grid has reportedly figured in determining the efficiency of industrial equipment in an interesting way. In order to make sure that the USSR-built industrial equipment installed in the DPRK would hold up under the prevailing conditions of poor power quality, Soviet engineers typically augmented (usually older) USSR designs to make the DPRK plants extra-rugged. These more rugged plants were thus probably more electricity-intensive, on the whole, than typical Soviet plants of the same types and vintages.

[71] 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. Japan uses both 50- and 60-cycle grids ("Listing of Countries with their Frequency and Voltage", provided on ZZZAP Power World-wide Web site http://azap.com/countries.html).

[72] Order-of-magnitude cost estimate obtained in conversation (1997) with G. Jutte of Siemens Power Transmission and Distribution, Limited. There are a number of 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 DPRK side, the distance over which the power must be transferred, and many others. The AC-DC-AC systems could also be used to inter-convert 50 Hz and 60 Hz power at the borders of the DPRK with China and Russia, suggesting that the $460 million interconnection cost listed above may be somewhat high (or may include different hardware).

- 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 ROK (and, ultimately, a unified Korea) be better served by revamping the DPRK system first to make it suitable to synchronize with the ROK grid (effectively creating one Korea-wide system), thus avoiding (at least some) power conditioning costs[73]?
- Would it be less expensive and technically less risky (again, assuming that the power from the PWRs is to be substantially sold to the ROK) to simply connect the PWRs to the ROK grid, but not (at least initially) to the DPRK grid? Doing so, of course, could face political difficulties quite apart from its practicality, 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 ROK border.

Status of Projects to Upgrade T&D System

Over the last several years, a project carried out by the United Nations Development Programme (entitled "Electric Power Management System") has been underway in the DPRK. The overall intent of this pilot project has been to install modern monitoring, modeling, and planning hardware and software in the Pyongyang EPPDCC to enable the grid operators to detect and model system conditions in real time. The project was to include monitoring and data transmission systems at eight remote locations on the grid, including four power plants and four substations. The pilot project, once completed, was to be replicated throughout the grid, so that ultimately power control and dispatching capabilities would be brought up to international standards.

At present, a personal computer-based local area network (LAN), complete with LAN software and software for modeling the T&D system, has been installed at EPPDCC, and operators have received some training in the use of the facilities. Microwave links with the eight remote power plants and substations have been established and activated, and the remote stations have been fitted with the necessary sensors and transducers for data acquisition. The hardware for the various components of the system was supplied by primarily Chinese contractors.

As of our last information, the DPRK and UNDP (in some combination) were preparing a pre-feasibility study to extend the system installed to the entire grid.

We do not know how well the systems installed under the pilot project are operating, or whether they have contributed significantly to overall system reliability in the DPRK.

Some of our assumptions as to the changes in the electricity supply system between 1990 and 1996 are described above. These changes as to changes in electricity supply, plus changes not mentioned above, can be summarized as:

- The addition to the system in the early 1990s of the first 50 MW unit of the (reportedly) 150 MW East Pyongyang coal-fired power plant

[73] A variant of this pathway has been proposed whereby the DPRK grid could be stabilized by adding gas-turbine plants along the ROK side of the DPRK/ROK border, and operating the gas turbines so as to maintain proper frequency on the DPRK transmission system. We do not know what additional investments to upgrade the DPRK grid would be required to make this proposed scheme technically feasible.

- The average 1996 capacity factor of coal-fired power stations is approximately 66 percent of the value we assume for 1990, or about 55 percent overall.
- Hydroelectric capacity from existing facilities falls by about 3,250 MW from 1990 values (to 1,250 MW) by 1996 as a result of flood damage[74] offset by additions to capacity[75]. Exports of electricity to China decrease to 28 percent of their 1990 levels.
- The average capacity factor of hydroelectric generating stations is at the same level as 1990, about 54 percent overall (but effective capacity is much lower).
- Thermal plants fueled exclusively with heavy fuel oil are assumed to have a 1996 capacity factor 71 percent of that in 1990, or about 52 percent overall.
- We assume that coal-fired plants use HFO in 1996 as both a start-up fuel and to augment poor quality coal, with HFO constituting about 6.2 percent of the total heat value of input fuel. Some of this HFO was supplied by KEDO.
- Transmission and distribution losses are assumed to be 50 percent higher, as a fraction of net plant output, than in 1990, as are "emergency losses" at thermal power plants. The efficiency of thermal power plants is assumed to decline due to lack of spare parts and general degradation of boiler systems (in part due to maintenance difficulties and in part due to the impact of using high-sulfur fuels).

2.4.2. Petroleum refining

The DPRK has two major oil refineries. Various estimates have placed the total refining capacity at these plants between 3 million tonnes[76] and 4.5 million tonnes[77]. Capacities in this range would be adequate to process the volume of crude oil that is reported to be imported (see above). Our best information is that crude oil imported from China via a pipeline was refined in the DPRK's 29,000 barrel per day (bpd, or about 1.45 million tonnes/yr[104]) Chinese-designed refinery in the northwest DPRK. This refinery was reportedly built in the late 1950s. It is designed to take Chinese crude oils (such as Daqing or Liaohe[105]). We assumed that the product slate of this refinery is the same as that of refineries of similar design in China, with product fraction (on a weight percentage of input basis) 45 percent HFO, 22 percent gasoline (low octane), 20 percent diesel oil, 4 percent kerosene, and 5 percent liquefied petroleum gas (LPG) and refinery gas[106]. The DPRK's other major refinery, located on the East Coast at Sonbong, has a capacity of 42,000 bpd (about 2.1 million tonnes/yr), with a reported fluid cracking facility of 7,300 bpd[78, 107]. As of 1990, this refinery probably processed much or all of the oil imported to the DPRK from the Soviet Union and from Middle Eastern countries.

---

[74] 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. Still another source with recent knowledge of the situation in the DPRK states that there has been significant siltation to reservoirs and possibly structural damage to some turbine-generators, and that the combined damage to the plants will take years to repair. This latter point of view is reflected in our DPRK energy supply-demand estimate for 1996. See additional discussion in Chapter 2.

[75] See discussion in Chapter 2.

[76] United Nations estimate, as cited in Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.

[77] It is not clear whether these figures are given per tonne of crude oil input or per tonne of product output.

[78] Some information about this refinery, and plans for its expansion, is available on the UNIDO (UN Industrial Development Organization) World-wide Web site at http://www.unido.org.

In addition to these two major refineries, some of our contacts have suggested that the DPRK has one or possibly two other smaller refineries, possibly used (when operating) to produce fuel for the military, with capacities no larger than 10,000 bpd, and likely much smaller. These are reportedly of the "fractionating tower" type, without cracking facilities. One or both may be associated with chemical production complexes. One of these units is located on the West Coast of the DPRK, and is associated with a small thermal power plant. We know nothing more about these units, but assume that their activity during 1990 and thereafter[79], if any, has been minimal due to (at least) lack of crude oil.

In estimating the energy used during refining, we have used a value for oil consumption during refining derived from Chinese data, namely 0.0578 tonnes oil equivalent per tonne of crude oil processed[108]. This yields an overall energy efficiency in refining of just over 94 percent, which is not unreasonable, but may prove somewhat high for the DPRK.

We have attempted, in preparing our estimated supply/demand balances, to account for production and consumption of the refined products separately (see Attachment 1). We have done this somewhat differently, however, in the 1990 balance than in our estimated balances for subsequent years. For 1990, we have essentially taken our estimates for demand by fuel, subtracted known imports, and then assumed that domestic production of petroleum products would meet the residual demand (less any exports). Our figures for 1990 refined products consumption--as measured by the fraction of total refined products demand accounted for by each separate product, differs from consumption data provided by Jang[109]. Data in the latter is taken from UN and IEA statistics, however, which may be suspect in the case of DPRK. For 1996 and beyond, we have used the fractions of refinery output by product, plus imports, to estimate fuel supply by product, and adjusted our demand estimates to (roughly) meet those supply estimates.

The DPRK's refinery in the Sonbong region (reported capacity of 42,000 bpd, or about 2.1 million tonnes/yr) probably processed the load of Libyan crude oil that the DPRK received in 1995, but has reportedly been in mothballs (inactive) for most of the last several years. We assume that only the DPRK's refinery near the Chinese border on the West Coast operated in 1996.

2.4.3. Coal production and preparation

Coal production in the DPRK is principally from underground mines (as opposed to open pit or surface mines), but most underground mines are not particularly deep. Much of the better coal in the large Anju field in western North Korea is unfortunately near or in fact under the ocean, which presents extreme mining difficulties due to the need to constantly remove seawater from the mines. Coal production in some mines in the DPRK is reportedly almost completely mechanized, but mechanization is apparently limited in other mines[110]. We applied Chinese figures from the 1980s for coal and electricity use during coal mining[111] to estimate the own use of these fuels during coal production in DPRK[80]. These estimates could be either low or high. The difficulties with water intrusion (for example) would argue that a large amount of energy

[79] An estimate for the operation of one of these refineries in the year 2000 is provided in Chapter 3 of this report.
[80] These own-use figures do not include the capture and combustion of coal-bed methane, which is employed in at least one DPRK coal mine.

would be expended for pumping, and thus these estimates would be understated[81]. On the other hand, the probable higher degree of mechanization in Chinese mines would argue that own-use would be lower in the DPRK than in China.

Coal washing is apparently not practiced in the DPRK, although it would be beneficial for many coal combustion applications. Coal briquetting is apparently practiced on a small scale--some briquettes are produced in hand presses--but no quantitative data on this preparation process were available to us[112].

For 1996, we assumed that coal and biomass production can meet demand, although coal production capacity has probably decreased somewhat as a result of flooding. We have heard that the coal mines in the important Anju district were flooded and badly damaged, which is entirely believable, as many of the Anju mines were below sea level to begin with. Despite the importance of this district, however, it did not produce a major fraction of the DPRK's coal even in 1990, when demand for coal was much higher than in 1996. As a consequence, unless flooding has caused long-term problems with transport facilities (and the DPRK seems to have mobilized very quickly to clean up flood damage in many areas), we suspect that the floods per se have had little lasting effect on coal production.

We have recently heard a report that the quality of coal produced in the DPRK has fallen significantly in recent years, and as of 1996 had an average energy content of no better than 1000 kcal per kilogram. By way of comparison, "standard" coal has an energy content of about 7000 kcal per kg (29.3 GJ per tonne); productive soils that are rich in organic matter (such as the "black soils" of the Russian steppes) have about the same energy content as has been reported for DPRK coal. If the average energy content of coal mined in the DPRK is really 1000 kcal per kg, it implies one of two things: either the actual mass (as opposed to the energy content) of coal produced in the DPRK in 1996 was about twice (some 140 or more million tonnes) that produced in 1990 (70 million tonnes), or our estimate of total coal production in 1996 is significantly in error, or some combination of the two. We would venture to guess that the average energy content of coal currently mined in the DPRK is probably significantly less than the 4500 kcal/kg that we used as an average value for 1990, but not as low as 1000 kcal/kg, though we certainly wouldn't rule out the possibility that even our fairly low value for overall 1996 coal production (in TJ) is too high. If indeed the average energy content of coal is in the vicinity of 1000 kcal/kg, the use of heavy fuel oil to augment coal in (particularly) utility and in industrial boilers becomes more important.

The reasons for the decline in coal quality in the DPRK reportedly center on the lack of spare parts for mining equipment (and probably diesel oil to fuel equipment) that can be used to open up new coal seams. Lacking sufficient working equipment, mining operations are forced to get what coal they can out of existing mines and seams, sometimes taking marginal coals that would, in better times, be left behind[82]. Another potential explanation for low recent coal production in the DPRK—an explanation that may also bear on the low energy content of the coal produced—takes into account social and political forces. An ROK observer has suggested

---

[81] It is reported (Document in authors' files [VO1]) that in some areas of the Anju field 6 m^3 of water must be pumped to mine a tonne of coal. It is not known how representative this situation is of the Anju field as a whole or of all mines in DPRK.

[82] Recent mining practices may have also included removing the pillars and walls of coal that had been left in the mines during more normal mining operations, allowing the mines to collapse as the coal in these structures is removed. In addition to being dangerous to miners, these practices, if actually carried out (and we have no corroboration that they have been), would imply premature destruction of coal mines, as areas allowed to collapse are rendered much more difficult to mine further in the future.

that coal miners in the DPRK “are mostly those classified as belonging to hostile social strata and, as such, not even provided with minimum human living conditions. Consequently, they are not eager to work at all” [113]. We do not know to what extent this assertion of coal miner antipathy is an accurate reflection of general conditions in the DPRK, or to what extent worker unhappiness acts to reduce coal production and/or coal quality.

2.4.4. Charcoal production

We have little information on the technologies used for charcoal production in the DPRK. Using a fuelwood input of 1 million cubic meters at 1.5 cubic meters per tonne[114], we assume an efficiency of 33 percent to yield a charcoal output of approximately 3.5 million GJ (gigajoules). An efficiency of 33 percent would be lower than that achieved in most commercial kilns in industrialized countries, but is probably somewhat higher than the average, for example, for earthen kilns in developing countries. We assumed that charcoal production continued to meet demand as of 1996.

2.5. Description of key results and uncertainties in 1990 and 1996 supply/demand balances

2.5.1. Energy Balances for 1990 and 1996

In this section we present our current best estimates, based on the information that we have reviewed, of an energy supply and demand balance for North Korea in 1990 and 1996. We intended and have treated these as “living” documents, that is, estimates that can be (and have been) updated as reviewers and others come forward with suggestions for improvements and with better information. We hope that the balances can be starting points for additional analysis and planning regarding the DPRK energy economy, including as bases for estimates of energy efficiency potential.

Although the balances that we have prepared are digests of a great deal of information, they also contain, necessarily, a great deal of conjecture on our part.

Units

Our summary, detailed, and petroleum products energy balances for 1990 and 1996 are presented as Tables 2-10 a to f, below, and as the first pages of Attachment 1. We have presented these balances in a standard energy unit, the *Terajoules (TJ)*, a unit equal to 1000 *Gigajoules* (GJ). In some cases (the summary balance) we express results in *Petajoules (PJ)*, a unit equal to a thousand terajoules or a million GJ. For those who may be more familiar with other units, some standard conversions are:

- 41.84 GJ per tonne of oil equivalent (toe)
- 41.84 TJ per thousand tonne of oil equivalent (ktoe)
- 4.184 GJ per million kilocalories (Gcal)
- 4.184 TJ per billion kilocalories (Tcal)
- 29.3 GJ per tonne of standard coal equivalent (tce)

- 29.3 TJ per thousand tonne of standard coal equivalent (ktce)
- 3.6 GJ per million watt-hours (MWh)
- 3.6 TJ per billion watt-hours (GWh)
- 1.055 GJ per million British Thermal Units (MMBtu)
- 6.1 GJ per barrel of oil equivalent (boe)
- 6.1 TJ per thousand barrel of oil equivalent (kboe)

Table 2-10a: Summary Estimated Energy Supply/Demand Balance for the DPRK, 1990

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/NUCL.	WOOD/ BIOMASS	CHAR-COAL	ELEC.	**TOTAL**
ENERGY SUPPLY	1,356	111	27	77	376	-	(12)	1,934
Domestic Production	1,318	-		77	350			1,744
Imports	68	111	27		27			232
Exports	30						12	42
Stock Changes								
ENERGY TRANSF.	(381)	(111)	89	(77)	(11)	4	111	(376)
Electricity Generation	(301)		(16)	(77)			166	(228)
Petroleum Refining		(111)	104					(6)
Coal Prod./Prep.							(9)	(9)
Charcoal Production					(11)	4		(7)
Own Use	(64)						(12)	(76)
Losses	(16)						(34)	(50)
FUELS FOR FINAL CONS.	974	-	115	-	366	4	99	1,558
ENERGY DEMAND	980	-	110	-	365	3	110	1,569
INDUSTRIAL	660	-	25	-	2	-	65	752
TRANSPORT	-	-	36	-	2	-	12	50
RESIDENTIAL	218	-	7	-	259	3	11	498
AGRICULTURAL	10	-	5	-	45	-	3	62
FISHERIES	-	-	2	-	-	-	0	2
MILITARY	38	-	19	-	-	-	9	66
PUBLIC/COMML	35	-	-	-	-	-	11	46
NON-SPECIFIED			6					6
NON-ENERGY	18		9		59			86
Elect. Gen. (Gr. TWhe)	23.43		1.28	21.29				46.00

Table 2-10b: Detailed Estimated Energy Supply/Demand Balance for the DPRK, 1990

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	ELECTRICITY	TOTAL
ENERGY SUPPLY	1,355,949	110,742	26,604	76,641	376,250	-	(11,886)	1,934,300
Domestic Production	1,317,960	-		76,641	349,583			1,744,185
Imports	68,392	110,742	26,604		26,667			232,404
Exports	30,403						11,886	42,289
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(375,470)	(110,742)	82,809	(76,641)	(10,667)	3,520	122,184	(365,007)
Electricity Generation	(295,227)		(21,645)	(76,641)			165,600	(227,914)
Petroleum Refining		(110,742)	104,454				(593)	(6,881)
Coal Production/Preparation	(63,900)						(8,654)	(72,554)
Charcoal Production					(10,667)	3,520		(7,147)
Coke Production								-
Other Transformation								-
Own Use							(12,408)	(12,408)
Losses	(16,343)						(21,761)	(38,104)
FUELS FOR FINAL CONSUMPTION	980,479	-	109,413	-	365,583	3,520	110,298	1,569,293
ENERGY DEMAND	979,947	-	109,710	-	365,475	3,435	110,302	1,568,869
INDUSTRIAL SECTOR	660,084	-	25,110	-	1,600	-	65,439	752,233
Iron and Steel	378,717						20,286	399,003
Cement	87,059		8,610				5,504	101,174
Fertilizers	23,994						18,891	42,885
Other Chemicals	11,203						6,616	17,819
Pulp and Paper	4,026						932	4,959
Other Metals	23,720						4,126	27,846
Other Minerals	-		12,600				396	12,996
Textiles	29,385						2,497	31,882
Building Materials	61,980						189	62,169
Non-specified Industry	40,000		3,900		1,600		6,000	51,500
TRANSPORT SECTOR	-	-	36,413	-	1,696	-	11,533	49,643
Road			30,288		1,696			31,984
Rail	-		1,949				10,533	12,482
Water	-		1,253					1,253
Air			1,123					1,123
Non-Specified			1,800				1,000	2,800
RESIDENTIAL SECTOR	218,440	-	7,300	-	258,562	3,435	10,718	498,456
Urban	117,956		6,441			3,435	7,420	135,253
Rural	100,484		859		258,562		3,298	363,203
AGRICULTURAL SECTOR	9,750	-	5,005	-	44,950	-	2,572	62,277
Field Operations			2,619				907	3,526
Processing/Other	9,750		2,386		44,950		1,664	58,750
FISHERIES SECTOR	-	-	1,947	-	-	-	100	2,047
Large Ships	-		1,747					1,747
Processing/Other	-		200				100	300
MILITARY SECTOR	38,467	-	18,812	-	-	-	9,008	66,287
Trucks and other Transport			6,585					6,585
Armaments			2,632					2,632
Air Force			2,648					2,648
Naval Forces			6,847					6,847
Military Manufacturing	887						48	935
Buildings and Other	37,580		100				8,960	46,640
PUBLIC/COMMERCIAL SECTORS	34,915		-		-		10,932	45,847
NON-SPECIFIED/OTHER SECTORS			5,700					5,700
NON-ENERGY USE	18,290		9,422		58,667			86,379
Electricity Gen. (Gross TWhe)	23.43		1.28	21.29				46.00

Table 2-10c: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK, 1990

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	110,742	5,272	12,954	6,220	2,159	-		137,346
Domestic Production	-							-
Imports	110,742	5,272	12,954	6,220	2,159			137,346
Exports								-
Inputs to International Marine Bunkers								-
Stock Changes								-
ENERGY TRANSFORMATION	(110,742)	25,314	19,344	16,932	8,843	11,627	1,080	(27,602)
Electricity Generation				(21,645)				(21,645)
Petroleum Refining	(110,742)	25,314	19,344	38,578	8,843	17,583	1,080	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
Other Transformation								-
Own Use						(5,956)		(5,956)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	30,586	32,298	23,152	11,002	11,627	1,080	109,744
ENERGY DEMAND	-	30,578	32,279	23,155	10,993	11,627	1,080	109,711
INDUSTRIAL SECTOR	-	-	3,500	21,610	-	-	-	25,110
Iron and Steel								-
Cement				8,610				8,610
Fertilizers								-
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				12,600				12,600
Textiles								-
Building Materials								
Non-specified Industry			3,500	400				3,900
TRANSPORT SECTOR	-	22,783	11,880	627	399	-	724	36,413
Road		22,783	7,505					30,288
Rail			1,949					1,949
Water			627	627				1,253
Air					399		724	1,123
Non-Specified			1,800					1,800
RESIDENTIAL SECTOR	-	-	-	-	5,096	2,204	-	7,300
Urban					4,237	2,204		6,441
Rural					859			859
AGRICULTURAL SECTOR	-	-	5,005	-	-	-	-	5,005
Field Operations			2,619					2,619
Processing/Other			2,386					2,386
FISHERIES SECTOR	-	-	1,073	873	-	-	-	1,947
Large Ships			873	873				1,747
Processing/Other			200			-		200
MILITARY SECTOR	-	7,794	8,820	45	1,798	-	356	18,813
Trucks and other Transport		6,477	109					6,586
Armaments		452	2,179					2,632
Air Force		494			1,798		356	2,648
Naval Forces		371	6,432	45				6,847
Military Manufacturing								-
Buildings and Other			100					100
PUBLIC/COMMERCIAL SECTORS			-					-
NON-SPECIFIED/OTHER SECTORS		-	2,000		3,700			5,700
NON-ENERGY USE						9,422		9,422

Table 2-10d: Summary Estimated Energy Supply/Demand Balance for the DPRK, 1996

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR- COAL	ELEC.	TOTAL
ENERGY SUPPLY	697	43	31	19	367	-	(3)	1,153
Domestic Production	741	-	-	19	340	-	-	1,100
Imports	4	43	39	-	27	-	-	112
Exports	48	-	-	-	-	-	3	51
Stock Changes	-	-	7	-	-	-	-	7
ENERGY TRANSF.	(242)	(43)	15	(19)	(8)	3	49	(244)
Electricity Generation	(196)	-	(25)	(19)	-	-	79	(161)
Petroleum Refining	-	(43)	43	-	-	-	(0)	(0)
Coal Prod./Prep.	(36)	-	-	-	-	-	(5)	(41)
Charcoal Production	-	-	-	-	(8)	3	-	(5)
Own Use	-	-	(2)	-	-	-	(10)	(12)
Losses	(9)	-	-	-	-	-	(15)	(24)
FUELS FOR FINAL CONS.	455	-	47	-	359	3	46	909
ENERGY DEMAND	455	-	47	-	359	3	46	909
INDUSTRIAL	243	-	9	-	1	-	22	273
TRANSPORT	-	-	15	-	1	-	5	20
RESIDENTIAL	130	-	2	-	282	3	6	422
AGRICULTURAL	9	-	2	-	40	-	2	53
FISHERIES	-	-	1	-	-	-	0	1
MILITARY	38	-	16	-	-	-	5	59
PUBLIC/COMML	31	-	-	-	-	-	7	38
NON-SPECIFIED			-					-
NON-ENERGY	5		3		35			43
								-
Elect. Gen. (Gr. TWhe)*	15.71	-	0.91	5.32	-	-	-	21.94

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 2-10e: Detailed Estimated Energy Supply/Demand Balance for the DPRK, 1996

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	696,725	42,503	31,159	19,160	366,811	-	(3,328)	1,153,030
Domestic Production	740,694	-		19,160	340,145			1,099,998
Imports	4,018	42,503	38,556		26,667			111,744
Exports	47,987						3,328	51,315
Inputs to International Marine Bunkers								-
Stock Changes			7,397					7,397
ENERGY TRANSFORMATION	(241,525)	(42,503)	15,395	(19,160)	(7,787)	2,570	48,994	(244,016)
Electricity Generation	(196,429)		(24,694)	(19,160)			78,981	(161,303)
Petroleum Refining		(42,503)	42,503				(227)	(227)
Coal Production/Preparation	(35,912)						(4,863)	(40,775)
Charcoal Production					(7,787)	2,570		(5,217)
Coke Production								-
Other Transformation								-
Own Use			(2,413)				(9,649)	(12,062)
Losses	(9,185)						(15,247)	(24,431)
FUELS FOR FINAL CONSUMPTION	455,200	-	46,555	-	359,025	2,570	45,666	909,015
ENERGY DEMAND	455,161	-	46,547	-	358,948	2,554	45,885	909,095
INDUSTRIAL SECTOR	242,504	-	8,505	-	528	-	21,909	273,446
Iron and Steel	148,782						7,970	156,751
Cement	31,003		3,407				1,960	36,370
Fertilizers	6,515						5,130	11,645
Other Chemicals	3,697		-				2,183	5,880
Pulp and Paper	1,329						308	1,636
Other Metals	7,828						1,362	9,189
Other Minerals	-		4,158				131	4,289
Textiles	9,697						824	10,521
Building Materials	20,453						62	20,516
Non-specified Industry	13,200		941		528		1,980	16,649
TRANSPORT SECTOR	-	-	14,910	-	814	-	4,670	20,394
Road			12,667		814			13,482
Rail	-		779				4,670	5,449
Water	-		564					564
Air			899					899
Non-Specified			-				-	-
RESIDENTIAL SECTOR	129,927	-	2,128	-	281,951	2,554	5,885	422,445
Urban	70,160		1,916			2,554	4,414	79,043
Rural	59,767		213		281,951		1,471	343,402
AGRICULTURAL SECTOR	8,775	-	1,502	-	40,455	-	2,315	53,046
Field Operations			786				816	1,602
Processing/Other	8,775		716		40,455		1,498	51,444
FISHERIES SECTOR	-	-	973	-	-	-	50	1,023
Large Ships	-		873					873
Processing/Other	-		100				50	150
MILITARY SECTOR	38,290	-	15,702	-	-	-	4,518	58,510
Trucks and other Transport			5,735					5,735
Armaments			2,290					2,290
Air Force			2,135					2,135
Naval Forces			5,443					5,443
Military Manufacturing	710		-				38	748
Buildings and Other	37,580		100				4,480	42,160
PUBLIC/COMMERCIAL SECTORS	31,151		-		-		6,539	37,690
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE	4,515		2,827		35,200			42,542
Electricity Gen. (Gross TWhe)*	15.71		0.91	5.32				21.94

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 2-10f: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK, 1996

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	42,503	8,039	5,181	17,421	518	-	-	73,662
Domestic Production	-							-
Imports	42,503	8,039	5,181	24,818	518			81,059
Exports								-
Inputs to International Marine Bunkers								-
Stock Changes		-	-	7,397				7,397
ENERGY TRANSFORMATION	(42,503)	8,773	8,617	(8,972)	1,723	4,381	871	(27,107)
Electricity Generation				(24,694)				(24,694)
Petroleum Refining	(42,503)	8,773	8,617	15,723	1,723	6,795	871	0
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
Other Transformation								-
Own Use						(2,413)		(2,413)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	16,813	13,799	8,449	2,242	4,381	871	46,555
ENERGY DEMAND	-	16,836	13,768	8,449	2,242	4,381	871	46,547
INDUSTRIAL SECTOR	-	-	809	7,697	-	-	-	8,505
Iron and Steel								-
Cement				3,407				3,407
Fertilizers								-
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				4,158				4,158
Textiles								-
Building Materials								
Non-specified Industry			809	132				941
TRANSPORT SECTOR	-	10,013	3,715	282	320	-	579	14,910
Road		10,013	2,654					12,667
Rail			779					779
Water			282	282				564
Air					320		579	899
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	574	1,555	-	2,128
Urban					361	1,555		1,916
Rural					213			213
AGRICULTURAL SECTOR	-	-	1,502	-	-	-	-	1,502
Field Operations			786					786
Processing/Other			716					716
FISHERIES SECTOR	-	-	537	437	-	-	-	973
Large Ships			437	437				873
Processing/Other			100			-		100
MILITARY SECTOR	-	6,822	7,206	34	1,348	-	292	15,702
Trucks and other Transport		5,640	95					5,735
Armaments		394	1,896					2,290
Air Force		494			1,348		292	2,135
Naval Forces		295	5,115	34				5,443
Military Manufacturing								-
Buildings and Other			100					100
PUBLIC/COMMERCIAL SECTORS			-					-
NON-SPECIFIED/OTHER SECTORS			-		-			-
NON-ENERGY USE						2,827		2,827

Total Energy Use

Our balance shows a total of 1934 PJ of energy used by DPRK in 1990, or about 88 GJ per person in the country. By way of reference, this is almost four times the per capita energy consumption in China in 1990, and only about a third less than per-capita energy consumption in Japan in the same year[83]. By 1996, this total had decreased to 1153 PJ, or about 52 GJ per person, of which nearly one-third was biomass.

2.5.2. Energy supply, including exports and imports

Coal made up approximately 69 percent of the total energy supply in the DPRK as of 1990, with wood and biomass contributing the second largest portion to the total national fuel input at about 20 percent. By 1996, coal was 59 percent of supplies, and biomass contributed 32 percent. Hydroelectricity (counted at 3600 GJ per GWh electricity generated) accounted for about 4 percent and 1.7 percent of the national energy supply in 1990 and 1996, respectively, with imported crude oil and refined products supplying the remaining 7 percent in both 1990 and 1996. Imports—about 50 percent crude oil, 28 percent coal, and 11 percent each wood and refined petroleum products in 1990—made up only about 12 percent of the total energy used in DPRK. The fractions of total energy imports accounted for by crude oil and coal decreased substantially in 1996. In the exports row for 1990, our balance includes only coal exports (at about 30 terajoules per year in 1990, and 48 TJ in 1996), and exports of electricity to China (about 12 TJ per year in 1990, and 3 TJ in 1996). Figures 2-4a and b show the fuel shares of the total DPRK energy supply for 1990 and 1996, while Figures 2-5a and b shows the components of exports, imports, and domestic production by fuel type and for all fuels.

[83] Figures for China (from Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900) do not include biomass energy use. Biomass energy use is a relatively large factor fraction of total fuels use in the case of China, but minimal in the case of Japan.

Figure 2-4a:

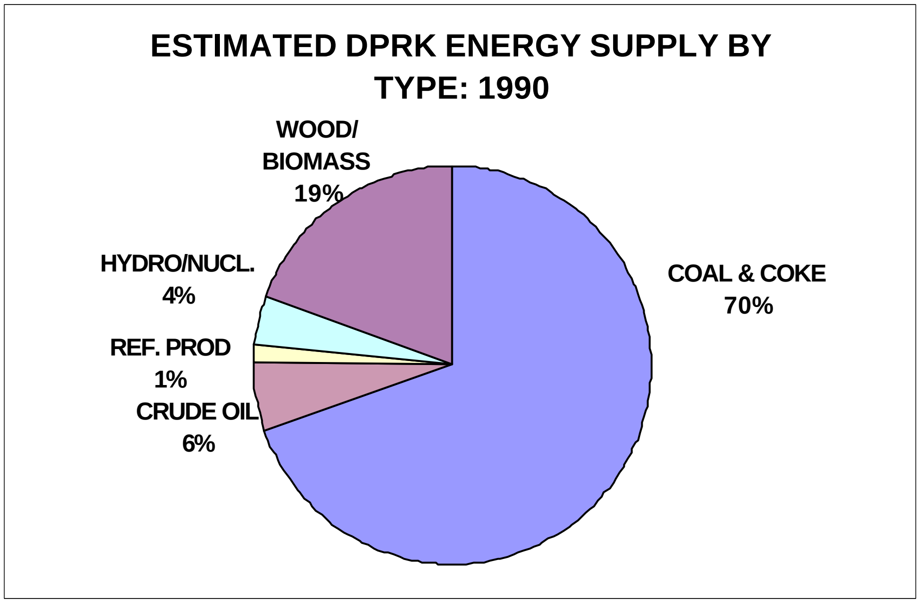


Figure 2-4b:

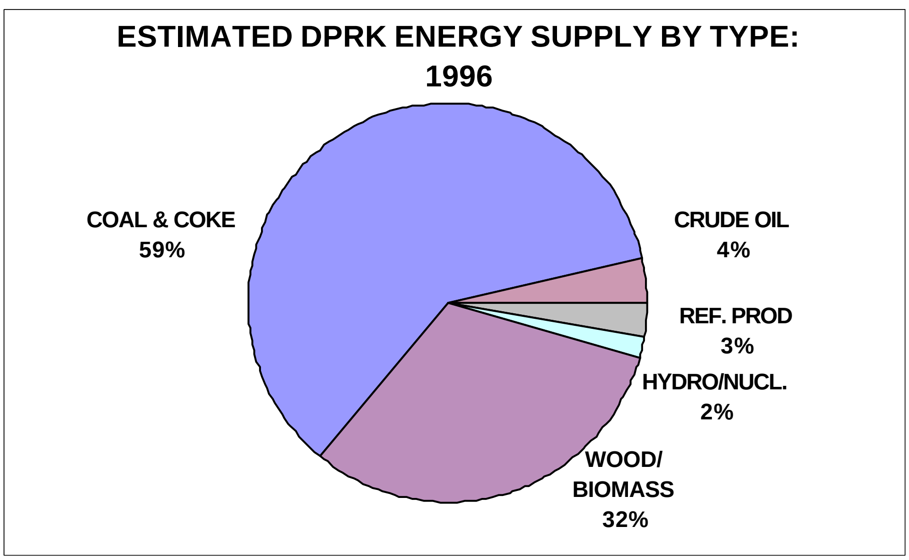


Figure 2-5a:

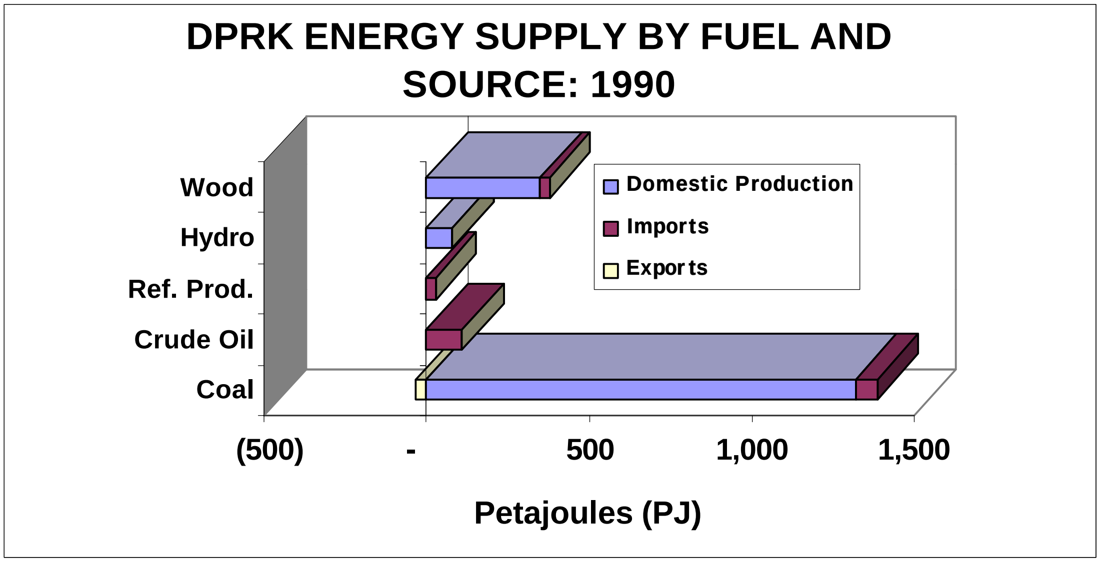
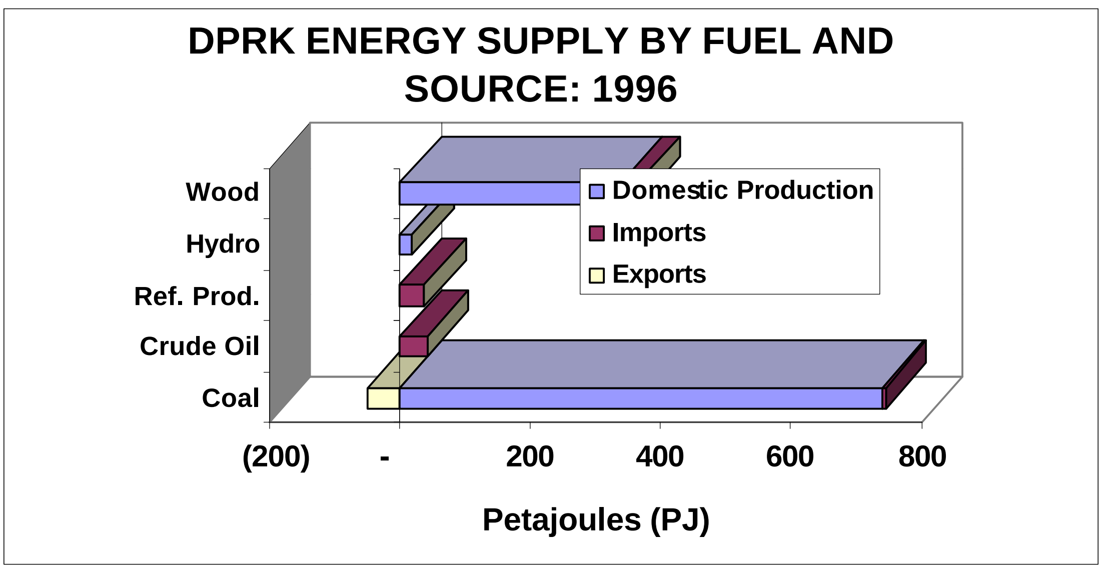


Figure 2-5b:



2.5.3. Energy transformation results

The results of the energy transformation portion of our estimated supply/demand balance for the DPRK are as follows:

- Electricity generation is the most important energy transformation process in the DPRK, consuming 22 percent of all of the coal and coke supplied, 17 percent of refined petroleum products, and all (by definition) of the hydro energy used in 1990, and 28 percent of coal and coke plus 79 percent of refined products (mostly KEDO HFO) in 1996.

- Petroleum refining uses all of the crude oil imported to the country, and produced roughly 80 percent of the refined products used in DPRK in 1990, as opposed to approximately 60 percent of refined products in 1996. Petroleum refining losses (own use) amount to approximately 5.7 percent of the crude oil input to refining.
- Coal production used 8.7 PJ of electricity, just over 5 percent of gross national generation, and 4.9 PJ in 1996 (6.2 percent of generation).
- In 1990, charcoal production consumed 10.7 PJ of wood, producing 3.5 PJ of charcoal. Charcoal production in 1996 consumed 7.8 PJ of wood, producing 2.6 PJ of charcoal.
- "Own use" of fuels occurs for two fuel types: coal and electricity. The coal is consumed in coal mining operation at a rate equivalent to just under 5 percent of the total coal mined in DPRK. The use of electricity within electricity generating plants, including "emergency" losses of electricity, accounted for about 7.5 percent of gross electrical production in 1990, and 12.2 percent of gross generation in 1996.
- The "losses" category includes losses of coal (such as coal falling from coal trains, or blown as dust from coal piles) at an assumed 1 percent of total production. Electricity losses in 1990 totaled 21.8 PJ, 13.1 percent of total gross generation[84]. Losses in 1996 were proportionally higher, totaling 15.2 PJ, or over 19 percent of generation.

2.5.4. Energy demand in 1990 and 1996

Of the total final energy demand in the DPRK in 1990, 62 percent was estimated to be provided by coal, 24 percent by wood and biomass, 7 percent by electricity, 7 percent by refined petroleum products, and less than one percent by charcoal (Figure 2-6a). If charcoal and wood/biomass are excluded, the fraction of fuel demand provided by coal rises to 77 percent. Figure 2-6b shows energy demand by fuel for 1996. Relative to 1990, demand in 1996 showed a reduction in the shares of coal and petroleum products, and an increase in the share of wood and biomass.

[84] Note that this figure appears lower than the sum of the 10 percent transmission losses and 6 percent distribution losses that we assumed (based on official DPRK figures). This result is obtained because these factors were applied sequentially to the total net electricity generated after in-plant use and exports are accounted for.

Figure 2-6a:

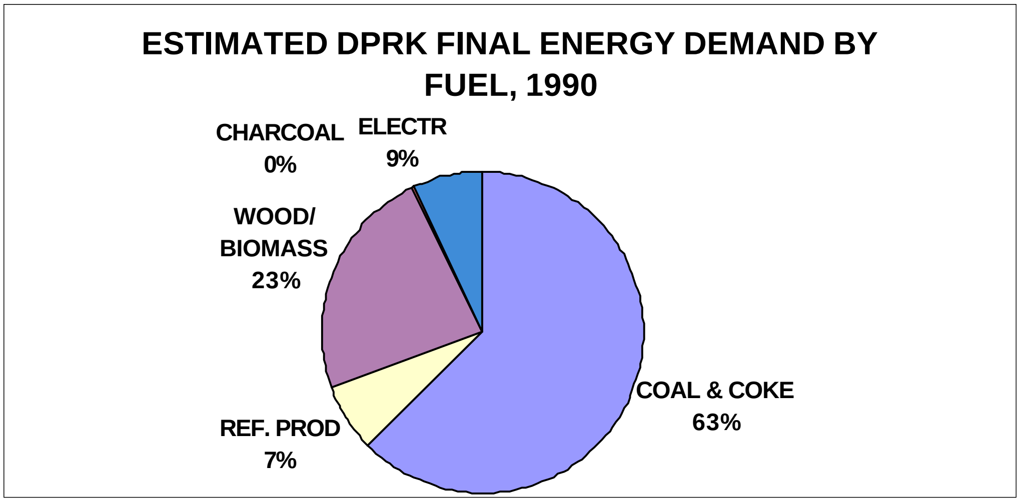
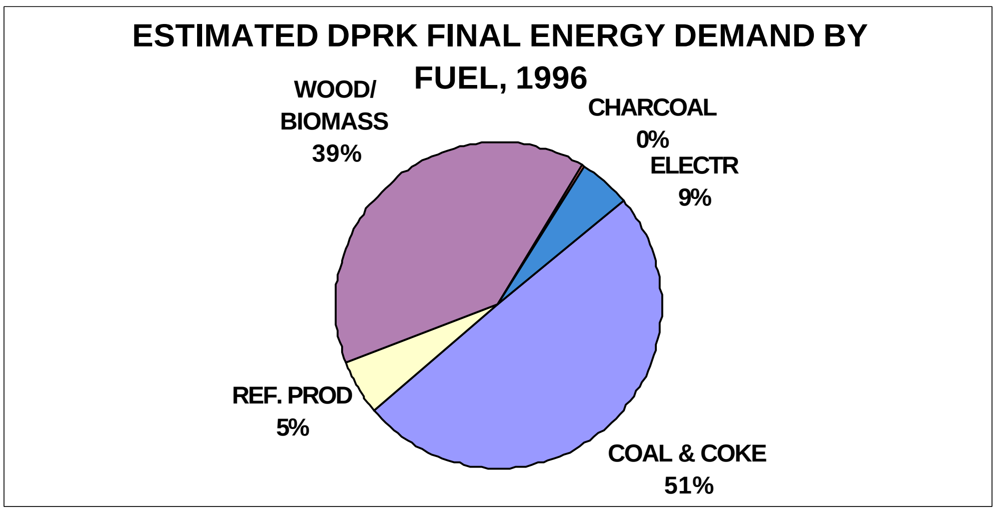


Figure 2-6b:



Looking at the sectoral shares of total energy demand, the industrial sector was estimated to be responsible for 752 PJ of total energy use, about 48 percent of all demand in 1990, but only 273 PJ (and 30 percent of demand) in 1996 (Figures 2-7a and b and 2-8 a and b). In 1990, the residential sector contributes 32 percent of demand (about half of which is wood and biomass), and the transport, agricultural, military, public/commercial, and non-energy uses each contribute between 3 and 5 percent to total fuel demand. The share of residential energy consumption increases markedly in 1996, due to the combination of reduced fuels use in other sectors and increased, relatively less efficient, use of biomass fuels in homes in rural areas.

Figure 2-7a:

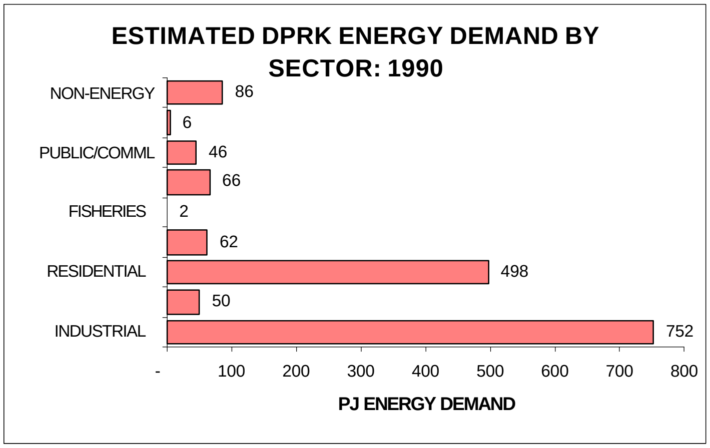


Figure 2-7b:

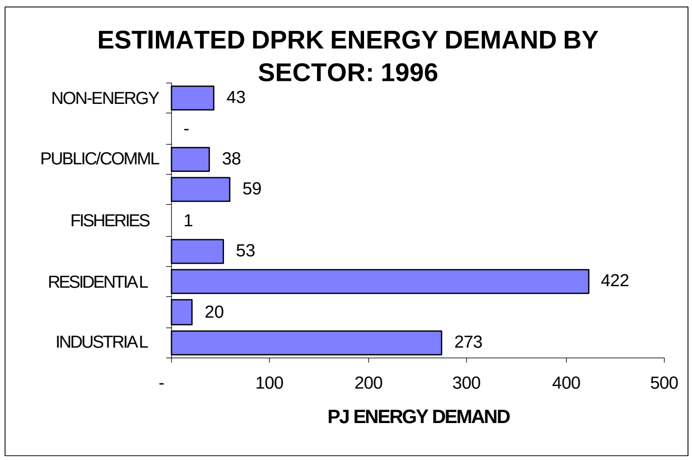


Figure 2-8a:

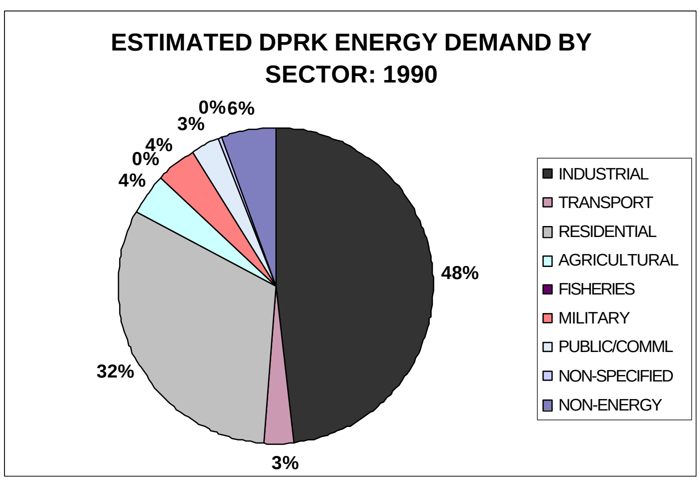
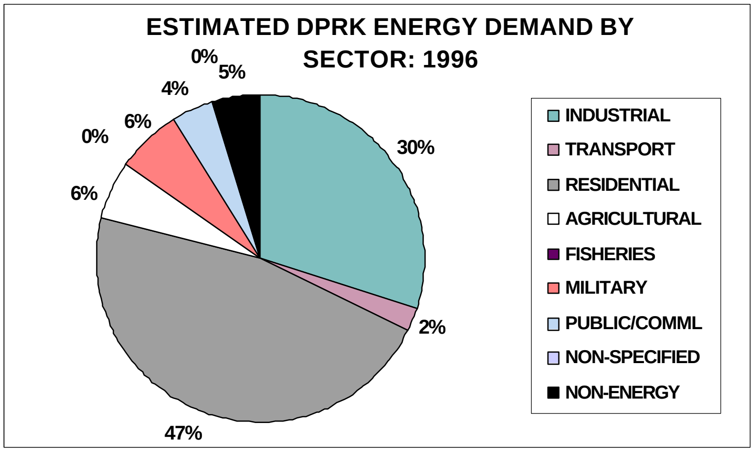


Figure 2-8b:



When consumption of specific fuels are considered, industry accounted for 67 percent of final demand of coal in 1990 (53 percent in 1996), while the residential sector accounted for 22 percent (29 percent in 1996), and others sectors contribute a few percent at most, with the military sector showing the greatest relative increase between 1990 and 1996 (Figures 2-9a and b).

Figure 2-9a:

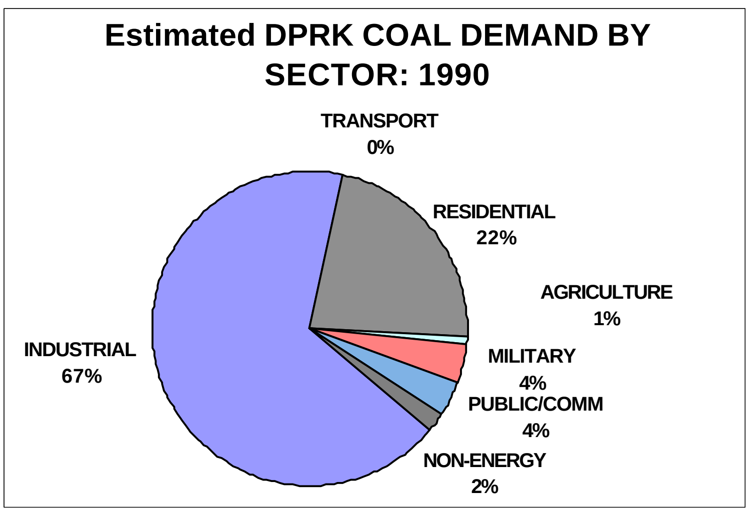
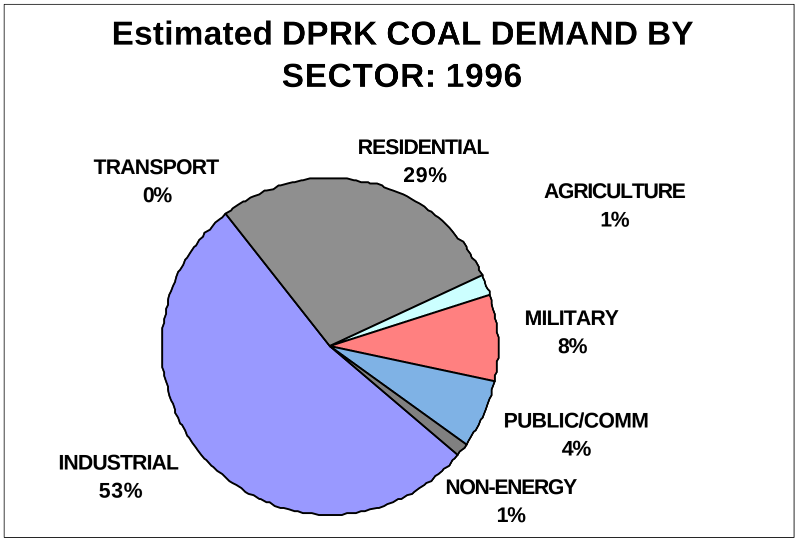


Figure 2-9b:



The major consumers of petroleum products in 1990 are estimated to have been the transport, industrial, and military sectors, with shares of 35, 26, and 19 percent, respectively (Figure 2-10a). Note, however, that the our estimate for industrial demand for oil products includes a rough estimate of oil use in magnesite production, an estimate of oil use in cement that is a guess, at best, and a placeholder value to account for what we estimate could be the rest of industrial oil demand. Our estimate of the shares of refined products consumption accounted for by the various fuel types (Table 2-10c) varies in several ways from the estimates of production by product provided by Jang[115]. The major difference is that our balance includes much more use of heavy oil. Figure 2-10b shows the pattern of estimated petroleum products demand as of 1996, which differs from the 1990 pattern primarily in that military use of these fuels accounts for a much larger fraction, with substantial decreases in the fraction of petroleum products used by the residential, industrial, and non-energy sectors.

Figure 2-10a:

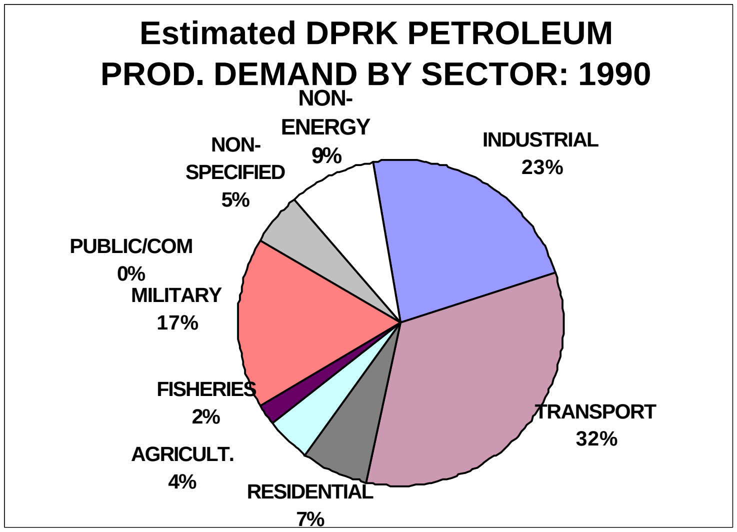
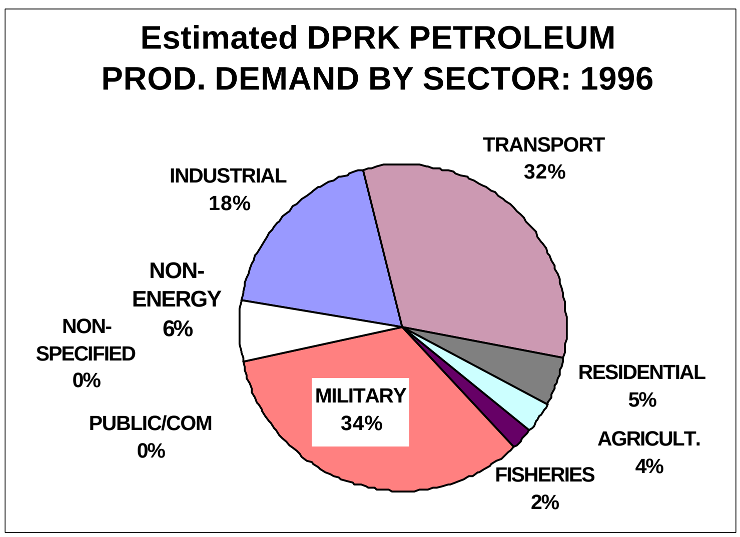


Figure 2-10b:



Industries in DPRK in 1990 are estimated to have used 58 percent of all electricity available for final demand. The transport sector (electric rail) is estimated to use 12 percent, residences 10 percent, the military 8 percent, and the public/commercial sector approximately 5 percent of the electricity supplied to end-users (Figure 2-11a). The pattern for 1996 is shown in Figure 2-11b.

Figure 2-11a:

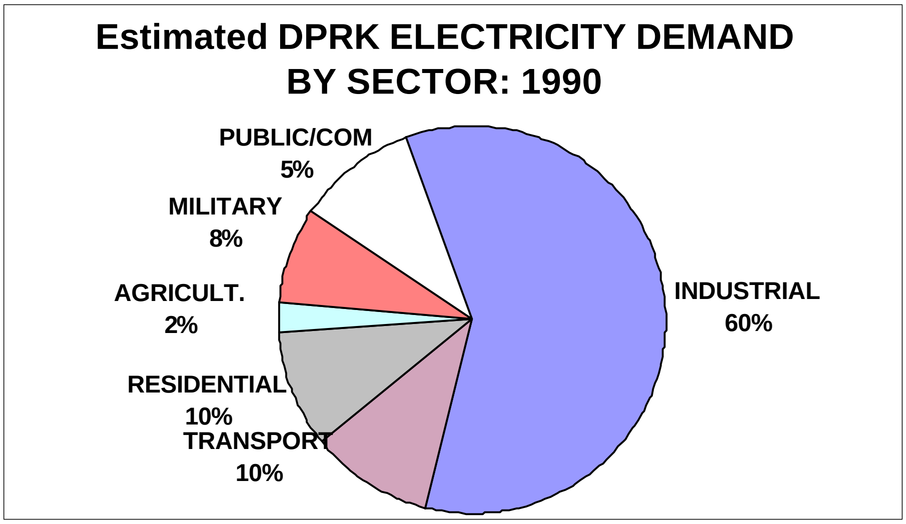


Figure 2-11b:

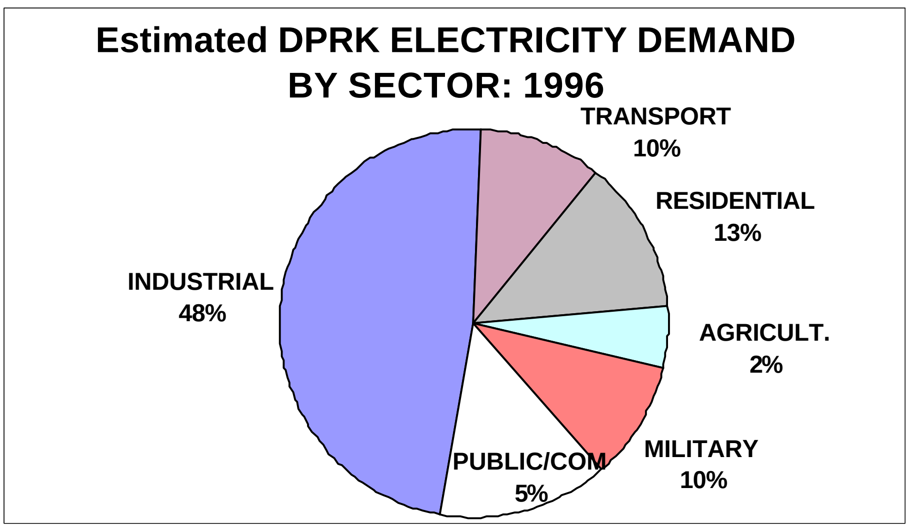


Figure 2-12a shows the estimated 1990 DPRK *Industrial* energy demand by fuel and by subsector. Coal is the dominant fuel in all subsectors except "Other Minerals", where we have included an estimate of petroleum products used for carbide production. The iron and steel production subsector is the largest consumer of coal in our estimate (over half of sectoral use, as shown in Figure 2-13a), while iron and steel, fertilizers, other chemicals, and cement are together responsible for approximately 80 percent of industrial sector electricity use (Figure 2-14a). The cement industry is another major consumer of fuels, accounting for an estimated 13 percent of industrial coal demand and 6 percent of industrial electricity demand. As noted, non-specified industries—consumption in which is specified primarily by placeholder values—account for a substantial fraction of fuel use in 1990. We would hope to obtain better information in order to reduce this fraction. Figures 2-12b, 2-13b, and 2-14b present industrial sector results for 1996.

Figure 2-12a:

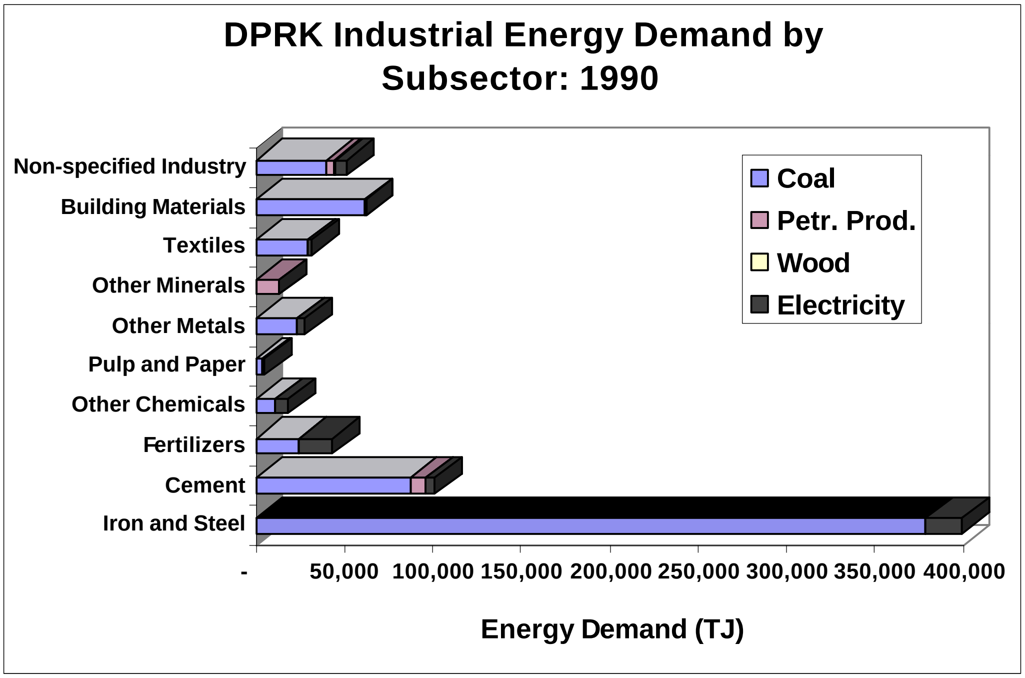


Figure 2-12b:

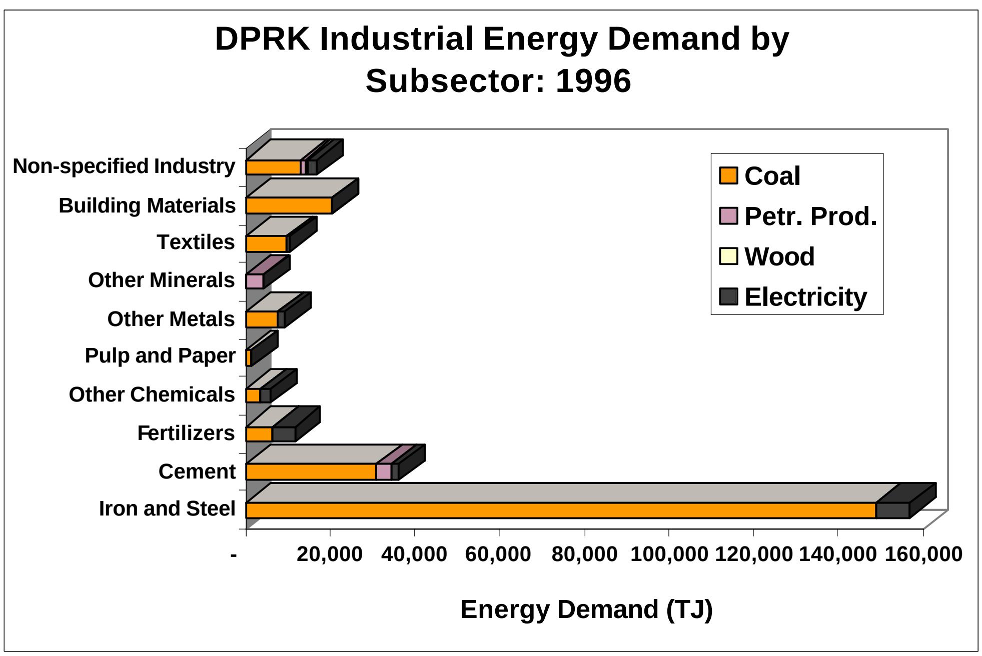


Figure 2-13a:

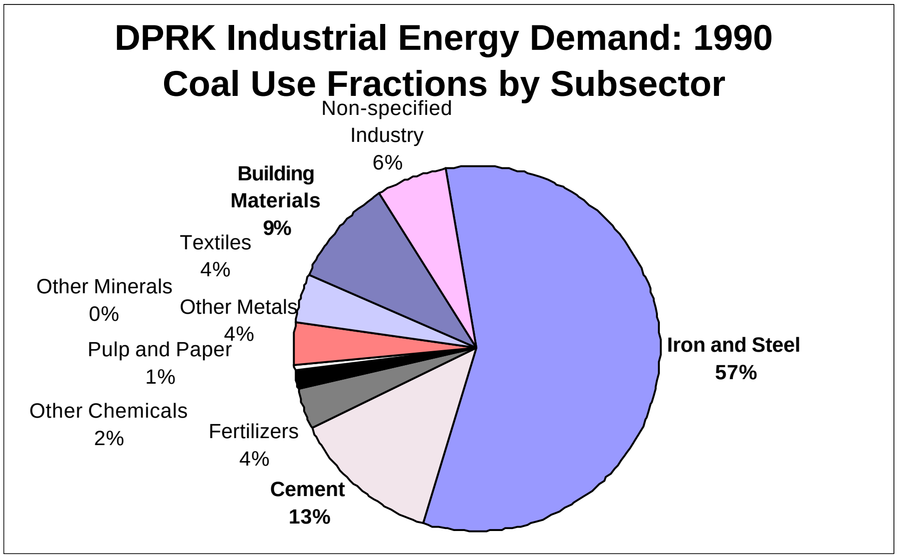


Figure 2-13b:

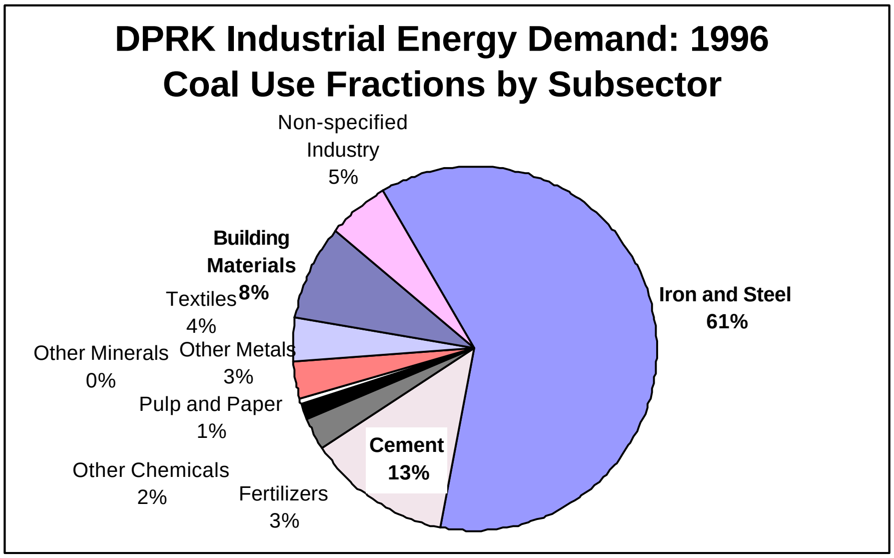


Figure 2-14a:

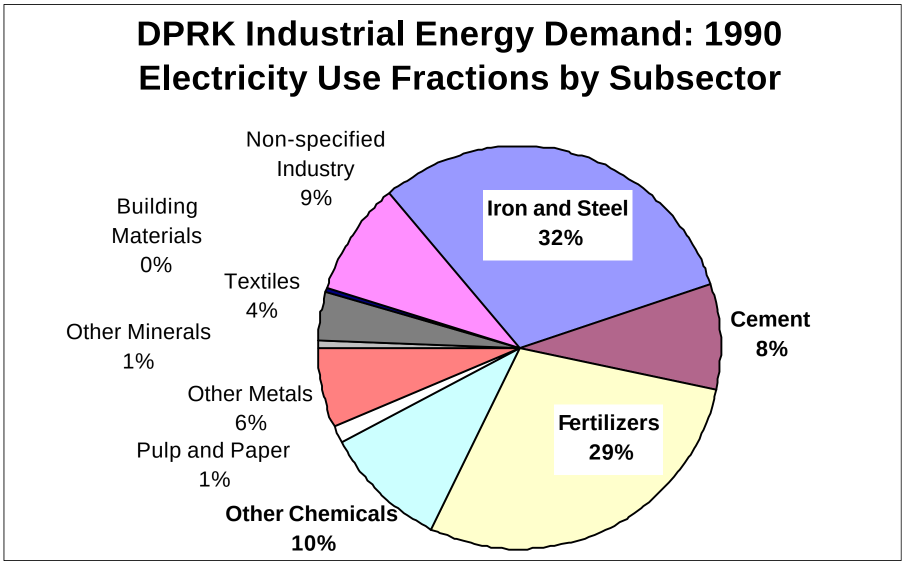
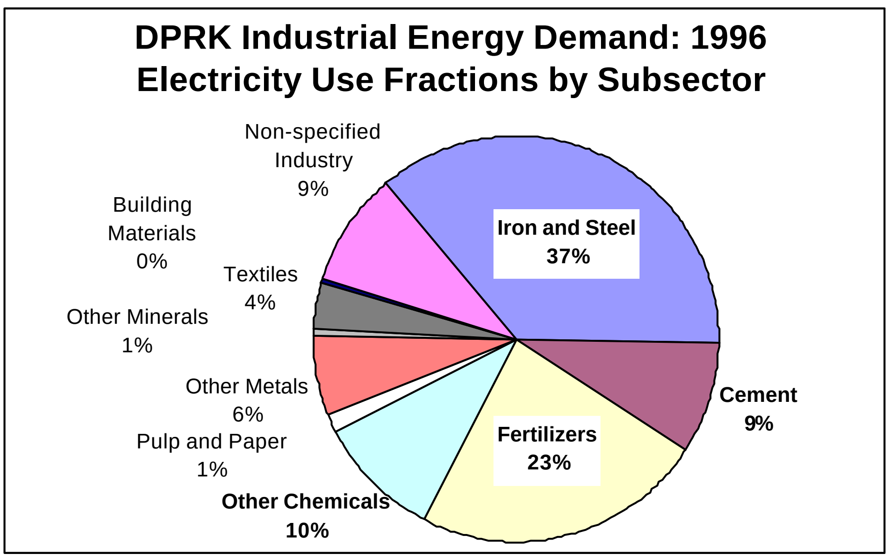


Figure 2-14b:



Transport sector energy demand as of 1990 was dominated by petroleum products used in the road transport subsector, as shown in Figure 2-15a. Again, the second greatest demand for fuels in the sector, as of 1990, was in the rail transport sector. The rail transport subsector is estimated to consume approximately 11,900 TJ of electricity, and less than one-fifth of that quantity of energy (1,950 TJ) in petroleum products (in this case, diesel oil). The air and water transport subsectors each use about 3 percent of total transport petroleum products use, though these values must be regarded, pending receipt of better information, as order-of-magnitude estimates only (see Figure 2-16a). Similar qualitative patterns in subsectoral consumption, but with much lower absolute levels of fuels use, are shown for 1996 (Figures 2-15b and 2-16b).

Figure 2-15a:

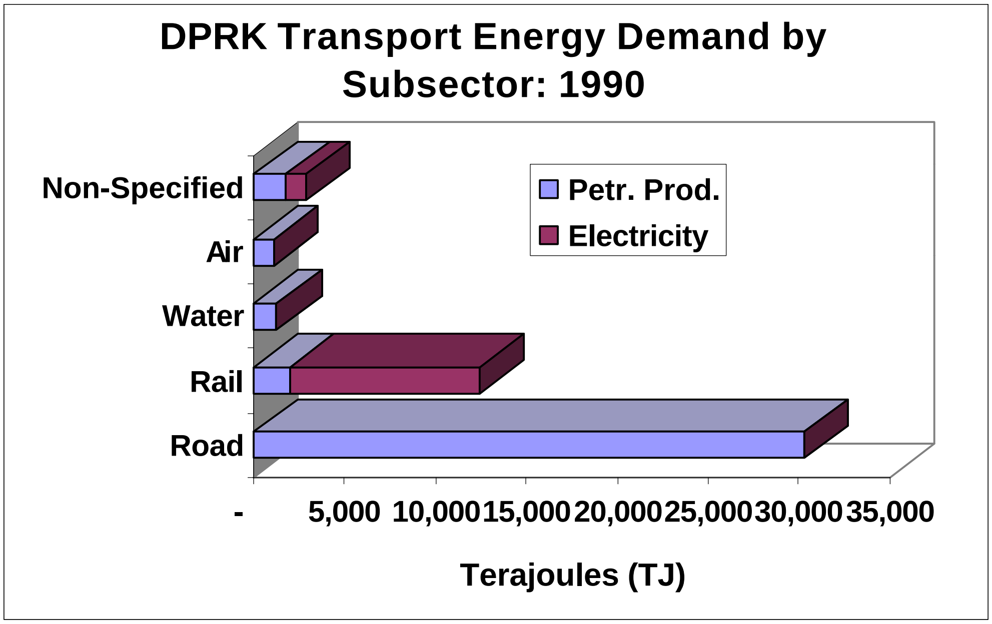


Figure 2-15b:

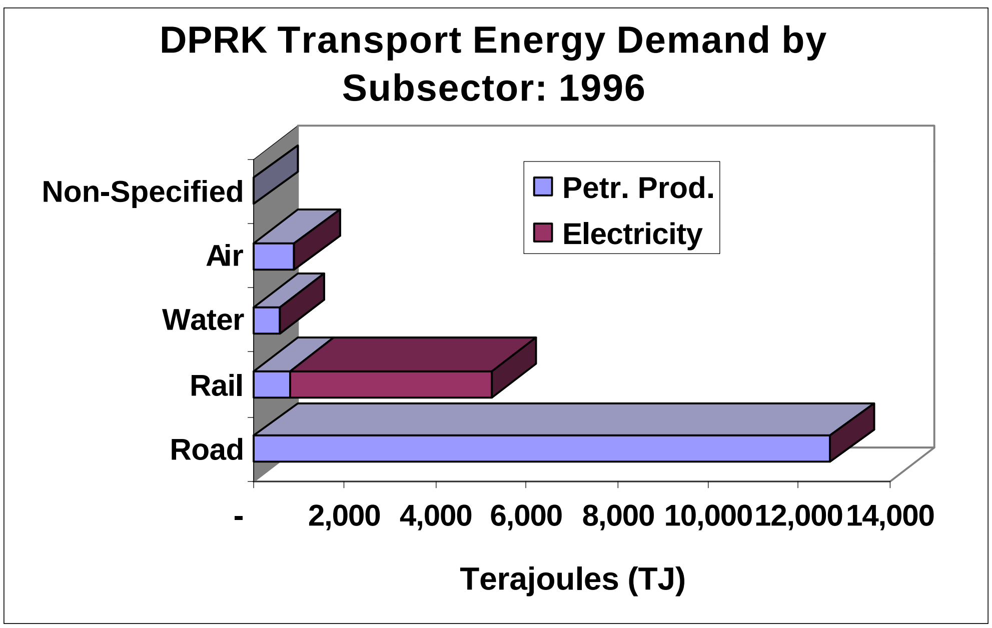


Figure 2-16a:

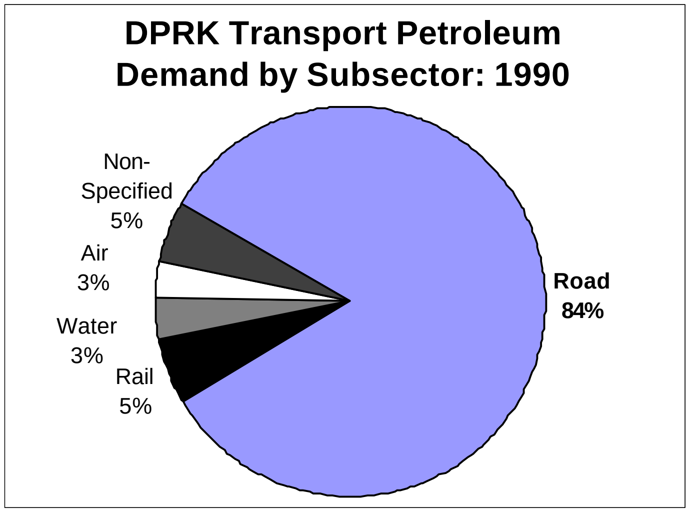
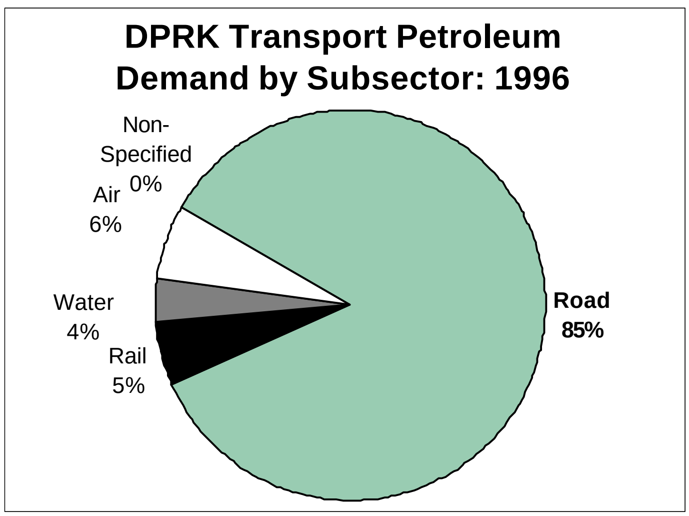


Figure 2-16b:



Demand in the *Residential* sector, as shown in Figures 2-17a and 2-17b (for 1990 and 1996 respectively), was dominated by coal and wood/biomass fuels. The urban and rural split of overall coal use by the sector is approximately even, while more than twice as much electricity is estimated to be used, in aggregate, in urban households than in rural households in 1990. This ratio is even larger in 1996. Wood fuel use is, by assumption, limited to the rural subsector, and amounts to approximately 14 tonnes of wood fuel use per household using wood fuel per year, or somewhat under 40 kg per day. Refined petroleum products (kerosene and LPG) and charcoal are assumed to be used for cooking in urban households, with LPG and kerosene also used in a limited number (5 percent) of rural households. Use of these fuels contributes less than two few percent to total sectoral energy demand. Demand for "commercial" (petroleum, coal, and electric) fuels in the residential sector declined significantly, in our estimate, between 1990 and 1996, while wood and biomass use remained at near-1990 levels.

Figure 2-17a:

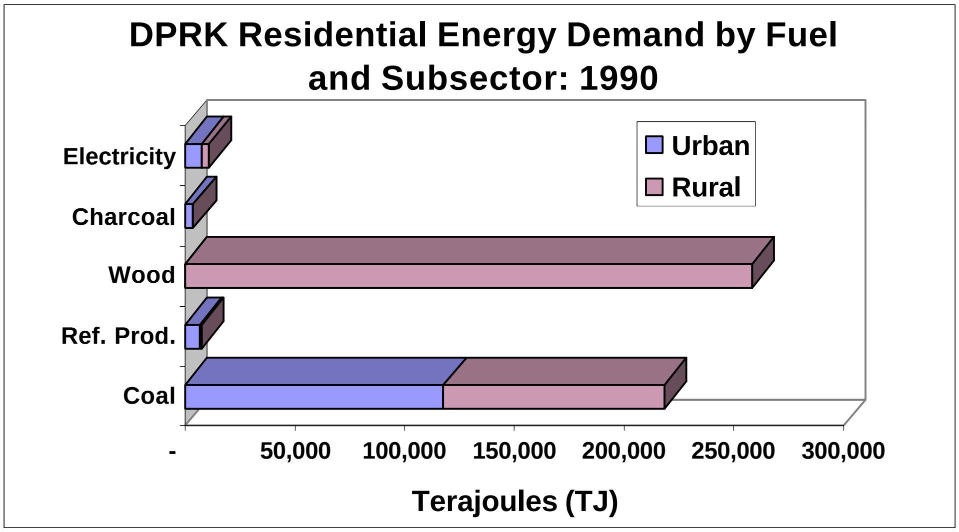
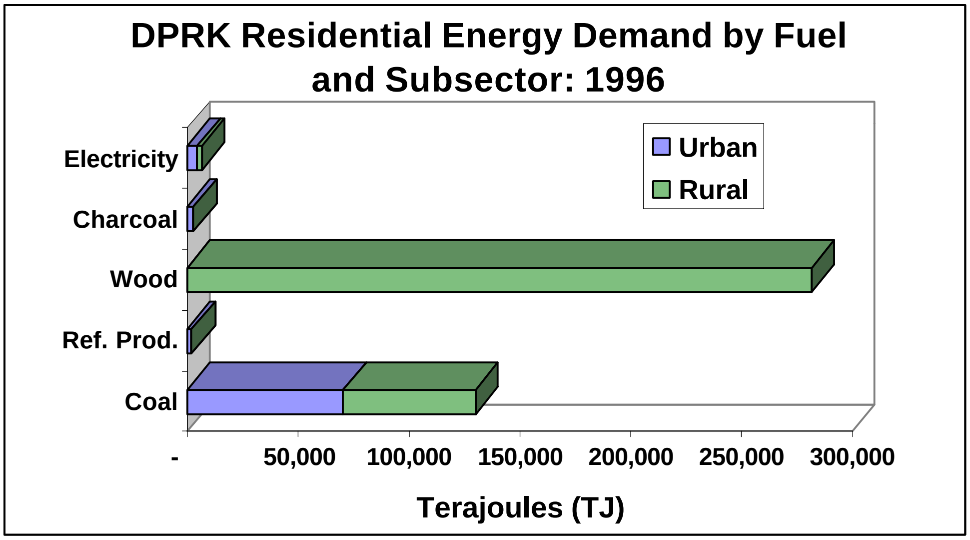


Figure 2-17b:



In the *Agricultural* sector, field operations and crop processing each contributed about half of total sectoral petroleum products demand in 1990, with a similar pattern in 1996. The use of coal is estimated to total about twice the use of petroleum products in 1990, and nearly six times as much in 1996, though the extent of coal use in crop processing is not known. In terms of overall fuel use, agricultural wastes used in crop processing dominate, accounting over 70 and over 75 percent of total sectoral fuel demand in 1990 and 1996, respectively.

Our estimate of demand in the *Fisheries* sector is fairly small, and quite uncertain. Most of the demand that we estimate for this sector is for diesel use by larger fishing craft. We have included a small amount of electricity use in the sector (100 TJ), but this amount could be significantly larger if the DPRK refrigeration/freezing capacity for the sector proves to be extensive. Fisheries energy use in 1996 is estimated to have been about half the level estimated for 1990.

For the *Military* sector, our estimate of fuel use is divided into two subsectors for ground forces: “trucks and other transport”, and “armaments”, including motorized guns and missiles, tanks, and armored personnel carriers. The other military subsectors are the Air and Naval forces, “military manufacturing”, and “buildings and other”. These divisions, and the amount of each fuel type estimated to have been used by the different military subsectors in 1990 and 1996, are shown in Figures 2-18a and 2-18b. Total estimated sectoral demand for coal and electricity is dominated by use in military buildings (57 and 14 percent of total sectoral energy demand, respectively in 1990), although these estimates are based on speculative estimates of military building floor area that have yet to be confirmed.

Estimates of the shares of petroleum product use in various types of military equipment are shown in Figures 2-19a and 2-19b for 1990 and 1996, respectively. Notable results here include the large share of demand accounted for by 2 1/2 tonne trucks in use in the DPRK Army. When service vehicles from other service branches are included—and these are also likely to be 2 1/2 tonne trucks, for the most part—the share of estimated military oil use by these trucks climbs to 38 percent (in 1990). Aircraft account for about 11 percent of military petroleum demand in 1990, and somewhat less than that in 1996. Though aircraft use a great deal of fuel per hour of use, we have assumed that their use is limited, and this assumption limits oil demand in the Air Force subsector. Naval patrol craft also are estimated to have accounted for a significant share of sectoral oil demand (29 percent in 1990), as have tanks and other heavy armaments (14 percent in 1990). Overall, in 1990, ground forces consume just under 50 percent of total military petroleum products, with Naval forces contributing just under 40 percent, and air forces the remainder.

Figure 2-18a:

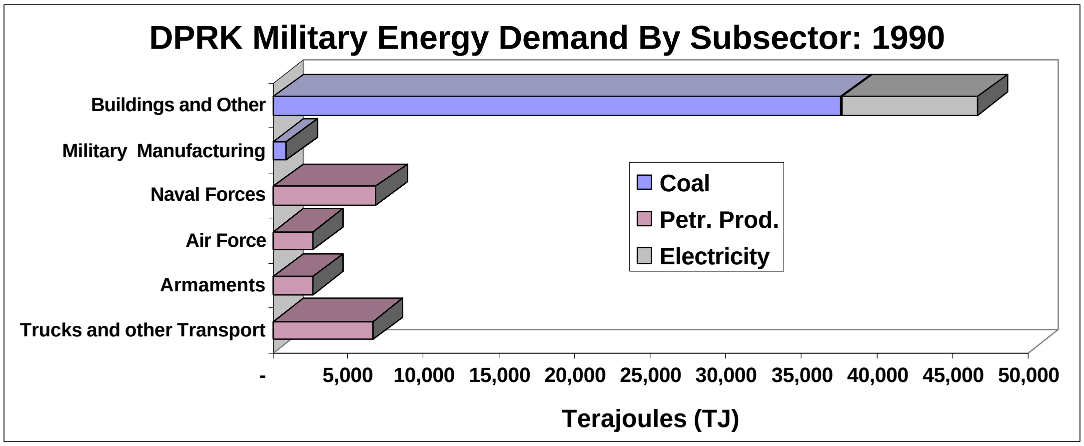


Figure 2-18b:

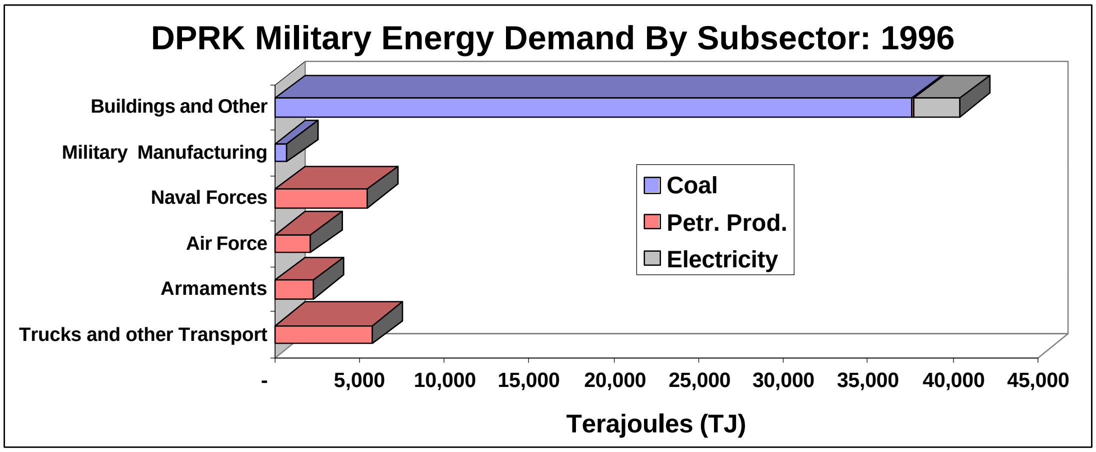


Figure 2-19a:

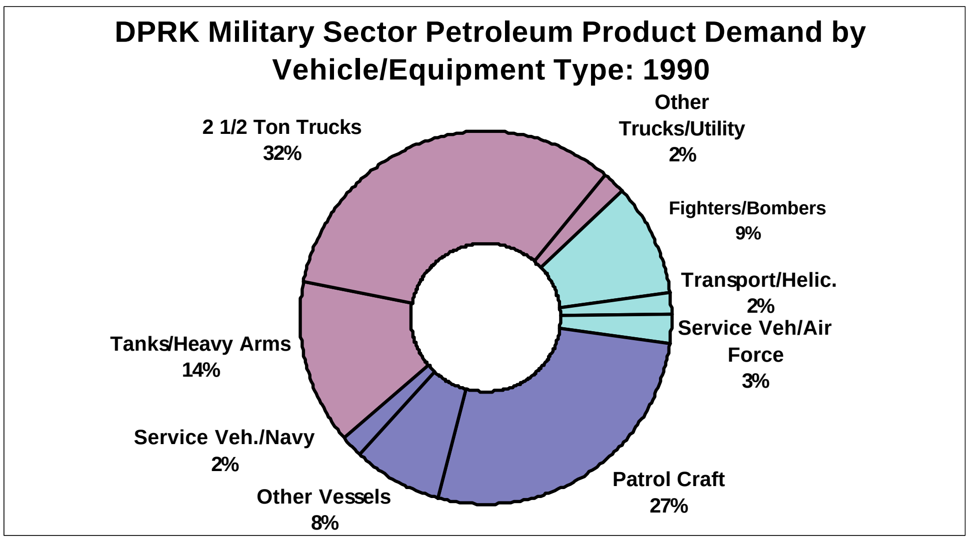
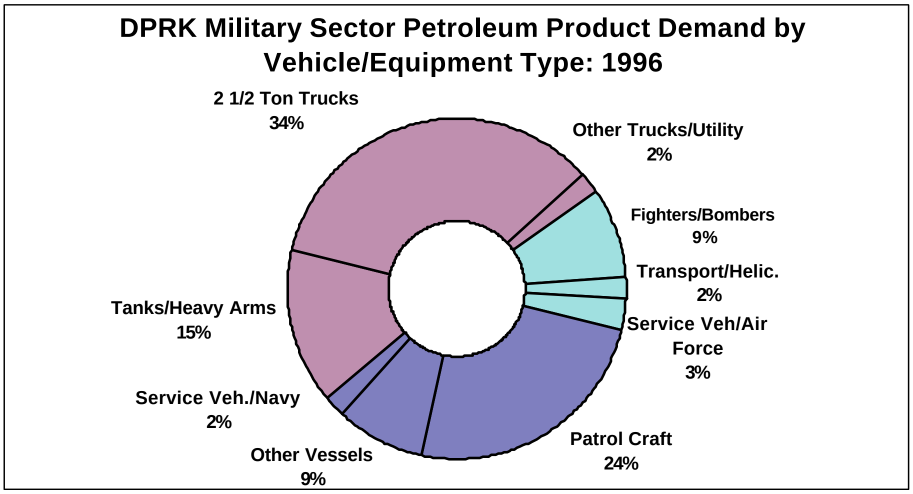


Figure 2-19b:



Our estimates of fuel demand in the *Public/Commercial* sectors are limited to coal and electricity used in public and commercial buildings, at roughly 35 and 11 PJ, respectively, in 1990, and 31 and 7 PJ in 1996. We have included a relatively modest 5.7 PJ of petroleum products demand in the "*Non-Specified/Other*" sector to assist in balancing petroleum product demand with reported supplies in 1990, but this value is set to zero for the 1996 estimate. In the *Non-Energy Use* category we have included coal used as a feedstock in fertilizer production and wood used for commercial purposes. These quantities were approximately 18 and 59 PJ, respectively, in 1990, and 4.5 and 35 PJ, respectively, in 1996. Non-energy petroleum products consumption in 1990 was estimated at about 9,400 TJ, roughly balancing our estimate of production of these products (although it is possible some of these non-fuel refinery products could have been exported in 1990). Non-energy petroleum products demand in 1996 has been estimated at the equivalent of 2.8 PJ (measured as the energy content of the products used).

2.5.5. Key uncertainties in 1990 and 1996 energy balances: Energy demand

There is no doubt that our estimated balance would benefit greatly from additional and better information in many (if not all) of the areas we have covered. Notable among these areas where additional information would be welcome are:

- *Industrial Sector*
    - -- Production of all fertilizers by compound, and specifically, production of fertilizers other than nitrogen and phosphorous fertilizers. Also need information on how superphosphate is produced in DPRK.
    - -- Production figures and energy intensities for additional key metals and non-metallic minerals produced in DPRK.
    - -- Confirmation that the iron and steel-making energy intensities we have used are reasonable (they are more likely to be too low than too high).
    - -- Information on the extent of heavy fuel oil use in the Cement industry, and information on other uses of petroleum products in the industrial sector.

- -- Information on extent of and feedstocks for production of other chemical products, including plastics and fibers other than vinalon.
- -- Information on the use of biomass and wood fuels and waste products in the pulp and paper manufacturing subsector.

- *Transport Sector*
    - -- Average figures for the haulage distance (or tonne-km) for freight carried by the various major transport modes--train, truck, and ship.
    - -- Use of personal transport in DPRK, in the aggregate as well as by mode.
    - -- Information on the number of vehicles in the DPRK bus, fleet, with their average annual km traveled and fuel economy.
    - -- Average hours of flight time, and composition, of the DPRK airline fleet.
    - -- Information on the contribution of DPRK to international aviation bunkers (if any).
    - -- Information on the extent, modes, and efficiency of biomass use in the DPRK transport sector.
- *Residential Sector*
    - -- Confirmation that our estimates of household size are not vastly in error.
    - -- Specific information on the average floor area and energy use (coal, electricity, cooking fuels) in urban apartments (or confirmation that our estimates are reasonable).
    - -- Better information on the use of petroleum products in residential cooking.
    - -- Confirmation that our assumption that rural fuel use data from specific areas in the DPRK can stand for the country as a whole is reasonable, or information that would allow us to calculate a better weighted average.
    - -- Average electricity use in rural households.
- *Agricultural Sector*
    - -- Confirmation that our assumption as to fuel use per hectare in production of field crops is reasonable, or better figures, if available.
    - -- Information on energy used for irrigation pumping, including the fuel type (that is, the relative ratios of diesel, gasoline, and electric pumps).
    - -- Information on the use of fuels in the processing of agricultural products.
    - -- Information on the use of fuels in producing orchard crops, including silk manufacturing[85].
- *Fisheries Sector*

[85] Silkworms are fed on the leaves of mulberry trees.

- -- Information on fuel used by the fishing fleet (larger ships), or at least information on the days per year that they are active.
- -- Information on energy use by fishing cooperatives (though this is probably minimal compared with that used by large ships).
- -- Data on the fuels used in processing fisheries products (and on the processing technologies/systems used).

- *Public/Commercial Sector*
  - -- Information on floor space in public/commercial buildings.
  - -- Better estimates for coal and electricity use per square meter in public and commercial buildings.
  - -- Information on any significant petroleum product use in the sector.
- *Military Sector*
  - -- Information on the average annual exercise tempos (hours per year in use) for military equipment, including tanks, trucks, light vehicles, planes, and naval vessels.
  - -- An estimate of what fraction of the DPRK's military hardware (by category) is typically operable/operated.
  - -- A more reasonable estimate of military floor space.
  - -- Any additional information on energy use in military buildings.
  - -- Information on major uses of fuels in for special military technologies aside from energy use in weapons/vehicles or military buildings (though such data are admittedly unlikely to be made available).
- *Non-Specified/Other Sectors*

-- Information on major demand sectors that we may have omitted.

- *Non-Energy Use Sectors*
  - -- Information on non-energy uses of fuels other than the few we have cataloged.

2.5.6. Summary of key data gaps and uncertainties: DPRK energy supply in 1990

- In the **Coal** sector, a wide range of different production estimates exist for 1990. The uncertainty (on our part) as to which estimate is more correct is compounded by uncertainty as to which average energy content is appropriate for coal produced in the DPRK.
- In the **Petroleum** sector, the statistics used are probably fairly accurate--and almost certainly not low--but should be confirmed if possible. Note that our initial estimate of demand for petroleum products appears to come up somewhat short of estimated petroleum products production (thus the use of placeholder values, for example, in "non-specified industry"—see section 3.2), thus it would be prudent to investigate whether the supply of these products is overstated, whether we have underestimated demand, or both.

- In the **Wood and Biomass** production sector, all of the figures available seem to be quite uncertain, but this lack of information is not unusual (even in countries where data access is not difficult) when it comes to statistics describing the use of these fuels. The production levels that we have used appear plausible, but better statistics on wood production and use, including a clear indication of the units of production (that is, solid or packed volumes, bone-dry, air-dried, or green weights) would be helpful. Our estimate for biomass production is predicated on total biomass use for fuel in the rural household subsector, which is a very uncertain estimate.

2.5.7. Summary of key data gaps: DPRK energy transformation in 1990

For **electricity generation** processes, the key need is for a substantiated, easily cross-checked value for overall electricity production. Other needs are:

- A complete accounting of all grid connected power generation facilities (capacity, location, dates of construction/updating, and availability for generation)
- An accounting, by class (size, thermal/hydro), of power plants not connected to the grid and connected only to local grids, including plants associated with industrial facilities (including industrial cogeneration)
- Information on district heating, from both heat-only plants and from electricity generation plants
- Updated values for plant efficiencies, own-use rates, and "emergency losses"
- Data showing the relationship between rainfall and hydroelectric generation (or potential generation)
- Information on the impacts of the 1995 and 1996 floods on major hydroelectric plants, and estimates of the work and time required to repair any damage to hydro reservoirs and equipment.
- Information on the status of fuel supplies to thermal power plants, including any shortages of fuel (and the cause of those shortages)

For the **Transmission and Distribution** system, important uncertainties include:

- The locations and design voltages of the complete set of power lines on the DPRK transmission grid
- The actual level of transmission and distribution losses
- The current status, capacities, and vintages of individual substations and regional control centers. This accounting of substations would include a description of the types of transformers now in use in DPRK substations[86]
- The kinds of conductors and poles are currently in use, and the status of the transmission lines themselves (for example, have they been heavily damaged by scavengers?)

[86] Older transformers in the US often contain large amounts of insulating oils known as PCBs (polychlorinated biphenyls). PCBs are quite toxic (to humans and other ecosystem elements), and should be disposed of with great care. If substations in the DPRK are to be replaced in great quantity, and prove to contain PCBs, the disposal of PCBs may prove to be a significant health, occupational, and environmental concern.

- The extent to which the DPRK electric system currently operates as a unified grid, and the extent to which it operates as a set of semi-autonomous regional of local networks.

Uncertainties and additional data needs in **other transformation sectors** include:

- In the **petroleum refining** sector, a better estimate of in-plant use of energy would be helpful, as would an idea as to the generation and use of electricity in refineries. A better idea of the output slate of refined products would be needed if the balance were to be expanded to account for production and consumption of more individual petroleum products.
- Better figures on in-mine uses of coal and electricity for **coal mining** are needed.
- Data on the types, capacities, and efficiencies of **charcoal** production facilities in DPRK are currently lacking.

2.5.8. Key uncertainties in 1996 energy data

The number of assumptions that we have had to incorporate in our estimate of energy supply and demand in the DPRK in 1996 are many. Hard facts about the recent energy situation in North Korea have been for the most part unavailable. Although our bottom-up method using physical and sector-by-sector balancing can handle some of the key uncertainties by forcing an explicit, cross-cutting consistency in the analysis, a number of key uncertainties have been are identified but not resolved in our method. In this section we highlight some of our major uncertainties regarding changes in the DPRK energy sector between 1990 and 1996.

- **Actual total generation in 1996**: we have various estimates of total generation in recent years, but do not know how much electricity was actually produced, or what fractions of the total have been from hydroelectric or thermal power plants.
- **Total generation capacity**: We have seen several different figures for total generation capacity in the DPRK, but do not have a definitive list of all of the plants that were reported to be grid-connected (including industrial cogeneration facilities), nor do we really know how much capacity was available or how much total generation has taken place in smaller plants not on the main DPRK grid.
- **The status of generation facilities in general**: Although it seems clear that there was enough capacity nominally available to generate the electricity called for in our estimated 1996 supply-demand balance, we do not know for certain what condition the generating plants in the DPRK were in, and so we do not know how much generating capacity was functionally available.
- **The status of large generation facilities now or recently under construction**: We do not know the status as of 1996 of several of the reported large thermal and hydroelectric plants that had been reported to be under construction. Also unknown is whether there was significant flood damage, as of 1996, to the sites of new dams (for example, the Kumgang Mountain project).
- **The status of the NK plants shared with/generating for China**: Were the conditions and/or capacity factors at these shared plants better or worse than the rest of grid as of 1996?
- **Status of the T&D system**: Was the T&D grid fully operational, at stasis, deteriorating, deteriorated, or somewhere in between? The status of the grid is one of the elements determining how much power was consumed during 1996. Some sources hold that it would

take an investment of $1 billion or more just to keep the system from getting worse, but others think that the system is not getting any worse at present. Recent reports indicate that power outages, at least in the Pyongyang area, are now relatively rare—in contrast to the 1992 to 1994 period when outages were common, even in Pyongyang.

- **New transmission lines**: How much progress (if any) had been made on constructing the planned 300 kV and 500 kV transmission systems by 1996 is unknown. The status of these systems would have an effect on the level of overall T&D losses, and on plans for connecting the PWRs to be supplied by KEDO to the DPRK grid.
- **Damage to coal mines**: We have assumed that sufficient coal mine capacity still existed to easily serve the constricted DPRK economy of 1996, but we do not know what the extent of flood damage to mines and mining equipment was as of that time.
- **Status of fuel transport infrastructure**: Were the fuel transport facilities (principally rail facilities) still sufficiently operable to transport the quantities of coal and other fuels that we estimated were used in 1996? Reserves of coal would not seem to be a problem, but lack of transport facilities due to lack of diesel fuel and/or lack of steel rails to repair the tracks, for example, would have created problems in providing fuel to industries and other users, which would have implications for both coal and electricity demand.
- **The constitution of HFO use in the industrial sector**. We have assumed that most of the heavy fuel oil used in the industrial sector as of 1990 was consumed for magnesite production and (to some degree) for cement production. We have been told that magnesite production in 1996 was much less than in 1990, but we do not know with any precision how much production has declined. If magnesite production had declined to less than the 300,000 tonnes that we have assumed for 1996, it means either that much more HFO was used to augment coal in coal-fired power plants, as a co-fired fuel for cement manufacture, as an emergency fuel additive in the transport sector[87], was used in some other way in the DPRK economy, or was somehow exported[88]. It is likely that HFO was used in other industrial subsectors as well, though the DPRK pattern seems to have been to use coal as a fuel and feedstock even in industries (such as production of synthetic fiber) where virtually every other installation in the world uses a different (that is, oil-based) feedstock to produce similar commodities.
- **The role of "unofficial" petroleum products imports**. We have tried to learn as much as possible about how oil and oil products were coming into the DPRK as of 1996, but uncertainties remain. How much oil crosses the Chinese and Russian borders in tanker trucks, train cars, coastal freighters, and individual barrels? Does the output of the small refinery in China that ships oil to the DPRK vary substantially from year to year[89]? Does the DPRK get a representative share of the output of that refinery, or are the products that the

[87] We have been told that in recent years, HFO has been used, by some technical means not at all clear to us, as a fuel for trucks and other internal-combustion-engined transportation equipment. The extent of this use of HFO is not known, but we assume that it has been minimal relative to other uses of heavy fuel oil.

[88] Export markets for HFO accessible to the DPRK may be limited, given a general glut of heavy fuel oil on the Asian market relative to other petroleum products.

[89] Our conversations with those who keep a finger on the pulse of the Chinese oil industry suggest that refinery capacity factors can vary from 50 to 80 percent depending on each refinery's allotment of crude oil input for the year (D. Fridley, personal communication, 1996).

DPRK receives weighted toward the lighter fractions (of which they are more in need)? Definitive answers to these questions could alter our 1996 oil products balance somewhat, but would probably have relatively little impact on the pattern of HFO supply and demand.

- **Biomass-fueled trucks**. Biomass trucks in the DRPK certainly existed in the period around and after World War II. Some of the people we have talked to swear that trucks fueled with producer gas generated in on-board gasifiers ("biomass trucks") predominate for goods transport outside Pyongyang. Others who have extensive experience in the DPRK profess to have seen them not at all or rarely. If biomass trucks are, contrary to our assumption, in relatively common use, it would indicate somewhat less tight supply of motor fuels in 1996. If, on the other hand, biomass trucks carry less than the 8 percent of road freight we have assumed, the availability of gasoline (and diesel) for other uses would decrease somewhat.

3. Estimated 2000 Supply/Demand Energy Balance

3.1. Overall Approach

Our overall approach to preparing a DPRK energy supply-demand balance for 2000 included:

- Starting with the estimates of demand and supply prepared as above for 1990 and 1996.
- Modification of the 1990/96 estimates of demand for fuels to reflect reports of recent changes in conditions in the DPRK. These included changes in population, continued reduction in the availability of oil products, observed changes in the transport system, and reported or implied reductions in industrial, agricultural and fisheries output. Reports as to the availability of electricity in different parts of the country also played a role in the estimation of year 2000 electricity demand.
- Revision of our 1996 estimates of electricity supply to meet 2000 electricity demand and to reflect information about recent changes in thermal and hydroelectric generating capacity (and its availability).
- Estimation of 2000 oil supply in a way that reflects available information, including the capacities, product slates, and utilization of the oil refineries in the DPRK, and quantities of refined products reported to be imported during 2000 (including product trades recorded in official statistics and products reportedly imported "unofficially").
- Revision of oil products demand as initially estimated to meet the overall supply for each of the major classes of oil products (heavy fuel oil, diesel oil, gasoline, and kerosene).
- Setting the level of coal and biomass supply to meet demand, and re-adjusting supply of other fuels as necessary to produce a rough balance in overall supply and demand.

Overall, our approach to preparing the year 2000 energy balance, in keeping with the paucity of information available (both inside and outside the DPRK) about the DPRK in general and about its energy sector in particular, was to obtain all the information remotely germane to the problem, sift through the information to see which pieces made sense, and fit with other data, and to try and use what was available to prepare an internally consistent energy balance. In so doing we collected information from reports by others, media reports, official statistics of DPRK trading partners, information on the DPRK from ROK government agencies, and the reports of visitors to and observers of the DPRK. In updating our 1990 /96 energy balance to 2000, we contacted a number of specialists in DPRK (and broader Northeast Asian) energy issues and economics, including those who visit the country, to obtain their data, thoughts and observations on recent developments the DPRK. Except where explicitly cited in the notes presented in Attachment 1 or in this chapter, these sources have chosen to remain confidential.

The key assumptions and data used in preparing our estimated supply and demand balance for electricity and other fuels are presented below by sector (for demand) and by fuel group (for supply). In each case, details of the data, calculations, assumptions, and sources used are presented in Attachments 1 and 2 to this report.

3.2. Summary of Key Changes in the DPRK Energy Sector Between 1996 and 2000

Changes in the DPRK energy sector between 1996 and 2000 have, for the most part, been of a substantially more incremental nature than the changes in experienced during the first half of the 1990s. Individual changes are discussed in section 3.3, below. Among the key changes (or continuing processes) for the energy sector between 1996 and 2000 are:

- A continuing **decline in the supply of crude oil** from China, significantly reducing the overall output of the DPRK's remaining (Northwest Coast) refinery.
- Continuing degradation of **electricity generation infrastructure** due to lack of spare parts, maintenance not performed, or use of aggressive (high sulfur) fuels such as high-sulfur heavy fuel oil and used tires in boilers designed for low-sulfur coal.
- Continuing degradation of **electricity transmission and distribution** infrastructure, resulting in much **reduced availability of electricity** in most parts of the country away from Pyongyang. Figure 3-1 presents a view of the lights of Northeast Asia from space in which it is clear that electricity is available in the DPRK only in highly limited areas.
- Continuing **degradation of industrial facilities** (including eyewitness reports of industrial facilities being dismantled for scrap), and the damage to industrial electric motors from poor quality electricity (electricity with highly variable voltage and frequency).
- Some **imports of used motor vehicles** (which are more efficient than existing DPRK vehicles).
- A continued decline in **production of cement and steel**.
- Evidence of significant international trade in **magnesite (or magnesia)**.
- Some increase in **military activity**, relative to 1996.
- Continuing difficulties with **transport of all goods, especially coal**.
- Difficulties in **coal production** related to lack of electricity, as well as mine flooding (in the Anju region).
- Some **economic revival**, but mostly, it seems, associated with foreign aid and/or with areas of the economy that are not energy intensive.

Figure 3-1: Northeast Asia from Space[90]

3.3. Key Input Parameters, Sources, Assumptions and Methods Used in Estimating Energy Supply-Demand Balance for 2000

Key parameters, sources, assumptions and methods drawn upon in preparing the estimated DPRK energy supply-demand balance are discussed below for key energy demand

[90] A similar image is available from http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4333.

sectors, fuel supply resources, and energy transformation processes. The specific parameters used, a printout of the intermediate and final results of the calculations in which they were used, and additional references to data sources can be found in Attachment 1 to this report.

3.3.1. Industrial sector activity

In the industrial sector, we assumed that year 2000 industrial output was 18 percent of 1990 levels in all subsectors except cement (29 percent), and fertilizers (11 percent)[91]. The building materials and "other minerals" sectors were assumed to have the same relative output as the cement sector[92]. We assumed, based on reports (and our own observations) of eroding industrial facilities, plus the probable impact of poor coal, oil, and electricity on industrial machinery, that the average energy intensity of industrial production was 115 percent of 1990 levels, up from our assumed 110 percent of 1990 levels in 1996.

3.3.2. Transport sector activity

We assumed that the amount of freight to be transported by road would scale roughly with the amount of activity in most industrial sectors, and thus be about 18 percent of 1990 levels. We assume that biomass (gasifier) trucks account for 8 percent of road freight (the same as in 1996) but that the share of freight carried by diesel trucks, including recently imported vehicles, increases to 30 percent. "Civilian" auto transport is assumed to be slightly decreased from 1996 levels, and (mechanized) passenger road and rail transport is also assumed lower than in 1996. Diesel rail freight is assumed to be 30 percent of 1990 levels, and electric rail freight also decreases to 30 percent of 1990 levels as a result of lack of availability of electricity. Air travel is slightly decreased relative to 1996.

In general, no specific data were available for the transport sector for 2000, so estimates of the parameters in these tables are rough figures based on the experiences of Nautilus staff and others in the DPRK. Visitors to the DPRK have generally noted a modest increase in the use of

---

[91] WWW.koreascope.com, in "Production of Major Industrial Items and World Ranking" (visited 6/3/02), lists the ROK production of steel in 1999 as 41 million tonnes. In "Economic and Social Comparison between the Two Koreas", on the same WWW site, the ROK's steel production is listed as being 33 times that of the DPRK, implying an annual production of about 1.24 million tonnes. This figure, about 18 percent of 1990 production levels, seems plausible (though possibly high), and was used for the year 2000. The same source, in its "Economic and Social…" page, lists a DPRK cement production of 4.1 million tonnes, or about 29 percent of year 1990 production, which again seems plausible. WWW.nis.go.kr/english/democratic/industry07.html, dated 2001, by the ROK National Intelligence Service, suggests that current supplies of fertilizer cover only 40 percent of fertilizer needs in the DPRK. Causes and Lessons of the "North Korean Food Crisis", by Tony Boys of Ibaraki Christian University Junior College (2000), lists total fertilizer supply in the DPRK in 1999 of 200 ktonnes of "NPK", of which 32% was produced domestically, 10% imported, and the remainder provided in aid. This would imply that about 11% of 1990 levels of fertilizer production were achieved in 1999. We adopt this same figure for 2000.

[92] With the exception of "Other Minerals" and "Building Materials", we assume that the level of activity in other industries relative to 1990 in the year 2000 is approximately the same as in the iron and steel sector. The building materials and other minerals subsectors are assumed to have activities relative to 1990 similar to the cement industry. The other minerals subsector includes magnesite (or, when processed like lime for cement, magnesia), which is a valuable export product. An industry source indicates that an 8000 tonne shipment of magnesia (although it may have been magnesite) arrived in Europe in early 2001. Japan imported $3.5 million worth of magnesia in the first half of 2000 (Korea Trade-Investment Promotion Agency data from http://www.kotra.or.kr/main/common_bbs, visited 6/3/02, "Trade Tendencies of the Major Countries"), which, if annualized and assuming a sales price of $US 100 to $200 per tonne (within the range suggested in Queensland Department of Minerals and Energy Mineral Information Leaflet No 5: MAGNESITE, dated January 1998, suggests exports of 35 to 70 thousand tonnes to Japan alone, which in turn suggests relatively active production of the mineral. On our trip to the DPRK in October of 2000 we saw working brick or tile production facilities, some of the very few active industrial facilities we saw during our time in the DPRK.

small "private" cars and mini-vans in the last several years. The use of other vehicles, however, seems to have stayed the same or decreased slightly, thus the slight decrease in vehicle use between 1996 and 2000 relative to 1990. No change in the efficiency of vehicles was assumed between 1996 and 2000, as any efficiency gains through the introduction of a few imported vehicles seems likely to be counterbalanced by continuing problems with the availability of spare parts. We saw many disabled trucks along the road in areas not far from Pyongyang during our visit in 2000.

3.3.3. Parameters of residential energy use in 2000

We assumed that the year 2000 population in the DPRK was roughly 21.7 million, and that roughly 60 percent of the population can still be classified as "urban"[93]. We assumed that residential coal use in both urban and rural settings was about 50 percent of 1990 levels (down 10 percent from 1996), but that the use of wood/biomass fuel, charcoal, and urban use of oil products was the same as in 1996 on a per-capita basis. The use of electricity in residences is assumed to be severely curtailed (by availability) relative to 1990. Visitors to the DPRK in 2000 describe electricity in Pyongyang as being generally available, but electricity in at least major portions of other cities being largely unavailable. Based on Korea Trade-Investment Promotion Agency (KOTRA) data[94] that lists the population of Pyongyang as 3.4 million, and assuming, based roughly on a record of electrical outlet voltage collected in Pyongyang and covering most of 2000, that Pyongyang suffered from blackouts for about 20 percent of 2000, and further assuming that residents of cities other than Pyongyang had power only 16 percent of the time, we estimate that the average consumption of power per household was about 34 percent of that in 1990. Nautilus Institute's rural energy survey in the village of Unhari, on the West Coast of the DPRK[95], suggested an annual average usage of 390 kWh per household per year, fairly close to the 1990 value estimated as described earlier in this report. During our mission to Unhari in 2000, we determined that householders virtually never had electric power available in their homes during the day, especially in the winter months. As Unhari is relatively close to Pyongyang, it is our expectation that the situation there is likely, if anything, to be better than that in many other rural areas. We therefore assume that the lack of availability of power limited rural residents to 10 percent of 1990 levels of electricity consumption in the year 2000.

3.3.4. Estimates of energy use parameters for the Agricultural and Fisheries sectors

We assumed that, with the exception of slightly increased (40 percent of 1990 levels instead of 30 percent) use of diesel tractors in the agricultural sector, fuels use for farming would be similar to that in 1996. In the fisheries sector, based on data on DPRK marine catch, we assumed that fisheries effort and energy use would be 42 percent on 1990 levels in 2000[96].

---

[93] The USDOE Energy Information Administration lists a year 2000 population of 21.7 million in its North Korea Country Analysis Brief (www.eia.doe.gov/emeu/cabs/nkorea.html, visited 5/2002).
[94] From http://www.kotra.or.kr/main/info/nk/eng/main.php3, visited 6/3/02.
[95] As reported on in "A Rural Energy Survey in Unhari Village, The Democratic People's Republic of Korea (DPRK): Methods, Results, And Implications", Asian Perspectives Special Issue, 2002, by D. Von Hippel and co-authors. A longer version of this study will be available as a Nautilus Report.
[96] The Korea Trade-Investment Promotion Agency (KOTRA) suggests that DPRK marine products catch decreased substantially between 1996 and 1997, but has increased somewhat since then. KOTRA data (from "Agriculture, Forestry, and Marine Products industries", available through http://www.kotra.or.kr/main/, visited 6/3/02) lists 1996 output of .876 million tonnes, and 1999 output of .664 million tonnes. A web page on "North Korea's Foreign Trade in 2000" from the same site lists the value of

3.3.5. Public/Commercial sector parameters

Based on visits to the DPRK in 1998 and 2000, commercial/public space does not seem to be under construction at an unusual rate (when there is construction at all), so the ratio of residential to commercial/public space is assumed to be 95 percent of that in 1990 (assuming, in fact, some closure of public buildings and shops since 1990). We assumed a fraction of electricity use relative to 1990—34 percent—that is a function of the same assumed average urban electricity outage rate used for the residential sector, namely that power outages in cities outside the Pyongyang area as of 2000 were by far the rule rather than the exception. The fraction of 1990 coal use per unit area assumed for 2000, 65 percent, reflects the assumption that coal availability is poor in many areas of the country.

3.3.6. Military energy use parameters in 2000

With the minor exception of the addition to the roster of marine vessels of some small submarines and some amphibious "Kong Bang" hovercraft, the vehicles, vessels, aircraft and armaments assumed in use for the DPRK military is much the same as in 1996 (and 1990) as in 2000. We have assumed, based on the modest information available in the open literature and on conversations with analysts, that ground forces military activity in 2000 was slightly higher (10 percent) than in 1996[97], while aircraft use was on the order of one third to one quarter less than the already low levels of 1996[98], and naval vessel use was about halfway between the levels assumed for 1990 and 1996[99]. The level of military manufacturing is assumed to remain the same in 2000 as was assumed for 1996, at 80 percent of the 1990 level of activity.

3.3.7. Non-specified and non-energy commodities demand

We have included no non-specified fuels demand in the estimated balance for 2000. For non-energy commodities included in the balance, we have assumed that coal used as a feedstock for ammonia production scales with overall fertilizer output, and is thus 11 percent of 1990

---

marine exports as having increased 9.4 percent between 1999 and 2000. If all fisheries production tracked export earnings (which is not necessarily the case, but assumed for the sake of argument here), the implied ratio of fisheries output between 1996 and 2000 is 83%. We further assume that fisheries effort (as reflected in fuel use) is proportional to fisheries output. Alternatively, end-of-1999 data based on the Economic and Social Comparison between the Two Koreas, published by the National Statistics Administration (December 2000) and provided on http://www.koreascope.org/english/sub/1/index3-h.htm, suggest that the DPRK fish catch in 1999 was 45.7 percent of the catch in 1990. This figure is very close to the 42 percent figure shown above.

[97] Analysts contacted regarding the "tempo" of recent DPRK military exercises, and reports in the media (for example, "NK Ground Exercises Up as Navy and Air Force Decline", Yoo Yong-won, www.chosun.com, 2001- 9-10) suggest that the DPRK military exercise tempo for ground forces has increased somewhat in recent years, but not substantially, and that some of the apparent increase in exercises may be an increase in the number of soldiers involved, but not necessarily the number of fuel-using vehicles and armaments. Accordingly, we assume that the average hours of annual use by ground vehicles in 2000 was 10 percent higher than in 1996.

[98] The informal opinion or analysts familiar with the DPRK military situation suggests that air force activity in the DPRK is, if anything, declining slowly, perhaps due to lack of fuel, probably due to lack of spare parts, and probably due to a recognition on the part of the DPRK military command that in a real conflict, the DPRK Air Force is unlikely, given the age and condition of its aircraft, to play a substantial role. Accordingly, we have assumed that DPRK Air Force training exercises have continued to decrease slowly since 1996, as reflected in the flight-hours estimates shown.

[99] There does not appear to be any definitive information of an unclassified nature that could be used to qualitatively estimate the level of activity in the DPRK naval forces as of 2000. Analysts contacted in researching this update, however, indicate that the DPRK Navy does not seem to be operating under any particular fuel restrictions, and that the level of incursions (from DPRK vessels) experienced in ROK waters seems to be fairly consistent with prior years. As a result, we have assumed that DPRK naval activity was somewhat more (in terms of activity per vessel) than in 1996.

levels. Non-energy petroleum products use remains at 1996 levels (30 percent of 1990 levels), and roundwood (logs) consumption declines to 50 percent of 1990 levels.

3.3.8. Energy resources, imports, and exports in 2000 [GOT TO HERE]

We based our estimates of energy resources, imports, and exports for 2000 on the following data and assumptions:

- Domestic coal and biomass resources are sufficient for any level of production that can be sustained by the DPRK infrastructure.
- In 2000, coal was imported by the DPRK from (at least) China (about 226,000 tonnes, including bituminous, coking, and unspecified coals) and Australia (about 31,000 tonnes), and exported to (at least) China (8,100 tonnes) and Japan (351,000 tonnes of anthracite)[100, 101, 102]. There may have been additional off-the-records coal imports from or exports to China, but we have no information about such transactions.
- Crude oil imports in 2000 were limited to the 389,000 tonnes reported (in China Customs Statistics) as imported from China[103], plus a very roughly estimated 190,000 tonnes of crude oil imported (from an unknown location--possibly by rail from Russia or China, or by ship from Russia, China or elsewhere) for use in the small West Coast refinery (see below).
- There have been reports that the DPRK "began to produce crude oil in a sea well off Sukchon County, South Pyongan Province" in 1998 (Lee Kyo Kwan, writing on www.chosun.com, "North Korea Exports Petroleum", probably sometime in 2001). This article suggests, without citing any specific figures, that DPRK production was significant enough to allow the reduction of petroleum imports. It seems clear that foreign companies have obtained the rights to drill in DPRK territorial waters, and that some exploratory wells have been drilled (though we do not know if drilling was active during 2000). We assume based on conversations with experts in the industry (who are informed by both industry news and a knowledge of the geology of the region—which generally consists of small pockets of oil that are difficult to extract), that any production from DPRK wells, if it did occur, was minimal.
- In 2000, refined products imports to the DPRK included products from the ROK (reported informally to be "off-spec" products, probably heavy oil and diesel fuel, and in not well-known quantities, but estimated at 50,000 tonnes), Singapore (probably gasoline and diesel totaling about 60,000 tonnes), and Japan (44,000 tonnes of kerosene or jet fuel, plus a minor amount of solvents, according to customs statistics), and China (a variety of products totaling about 117,000 tonnes). According to an industry source, barter trade with Russia may have produced imports of "gas oil and light crude" from Russia at "1.5 kbbl/day or less". We have assumed an average of 1500 bbl/day. These quantities are in addition to the 395,000 tonnes

---

[100] Chinese import/export data from China Customs Report 2000, pp. 1483-1495 (in Chinese).
[101] Estimated roughly based on data from "Democratic People's Republic of Korea Fact Sheet", from the Australian Department of Foreign Trade (www.dfat.gov.au/geo/dprk, visited 5/17/2002), which lists Australian exports of coal to the DPRK during "2000-2001" as having a value of $AU 1.7 million.
[102] From data in Japan customs statistics, http://www.customs.go.jp/toukei/info/index_e.htm.
[103] A similar quantity of crude oil imports from China was reported by KEEI in a workbook of DPRK energy statistics provided to Nautilus in April, 2002.

of heavy fuel oil delivered by KEDO during the 2000 calendar year[104]. We also assume that the DPRK continued to receive oil product imports equal to about half of the output of a refinery on the Chinese side of the China/DPRK border. These products are estimated to have totaled about 300,000 tonnes in 2000.

- Also listed under refined products are the imports of an estimated 25,000 tonnes of used tires from Japan and Taiwan for use as a boiler fuel (for electricity generation). Cargoes of tires from Europe have reportedly also been requested by the DPRK.
- Year 2000 exports of refined products from the DPRK include about 24,000 tonnes of mostly heavy oil exported to China. We also have assumed that the DPRK traded about 48,000 tonnes of heavy oil, probably to China, receiving in exchange sufficient asphalt to construct the new superhighway between Nampo and Pyongyang (finished in late 2000).

3.3.9. Data and assumptions regarding energy transformation processes in 2000

Below we present the key data and assumptions used for our estimate of year 2000 activity in the major fuels "transformation" sectors—coal production, oil refining, and electricity generation, transmission, and distribution. (Charcoal production is assumed to be sufficient to produce the modest quantities required.)

- We generally assume that **sufficient coal mining capacity is operable** to supply the DPRK economy at the low level of demand reflected in the 2000 balance. Some DPRK observers suggest that some large coal mines are operating, and media reports (many of them from DPRK agencies) mention the output of major mines. Other observers suggest that practically no large mines are operating, as a result of electricity shortages, but that some smaller, less mechanized mines may continue to supply residential and perhaps other users. The mines in the important Anju region, portions of which lie below the sea bed, reportedly continue to be flooded and inoperable, in part due to lack of electricity for pumping.
- We assume that the **East Coast refinery remains closed**, and that the **West Coast refinery** on the Chinese border (on the DPRK side) **continues to operate** when crude oil from China is available. As a consequence, the latter plant was assumed to operate at an average of 27 percent of capacity during 2000.
- There is apparently another **small** (capacity unknown) **refinery** on the DPRK's West Coast. This refinery is reportedly very basic, lacking any "cracking" capacity, and operating in batch mode as a "fractionating" unit to produce fuels, reportedly, for the military. We have "back-calculated" the output from (and input to) this plant based on assumptions about the product slate, the capacity factor of an associated 60 MW power plant that uses heavy oil from the refinery, and the efficiency of that plant. Please see Attachment 1 for details of these calculations.

[104] Note that, based on KEDO flow-meter-based estimates, approximately 200,000 tonnes of heavy fuel oil remained in storage in the DPRK as of the end of calendar 2000 (Korean Peninsula Energy Development Organization 2002 Annual Report, available as KEDO_AR_2002.PDF from www.kedo.org; page 10). As KEDO changed its practice of accounting for deliveries and estimated consumption of HFO (the definition of "HFO Years") between 2001 and 2002, it is not possible to definitively determine from KEDO annual reports how much HFO was estimated to be in storage as of the beginning of 2000, but KEDO data for months close to the end of 1999 suggest that HFO in storage at the beginning of 2000 was also close to 200,000 tonnes, meaning that consumption of HFO more or less matched HFO deliveries for the calendar year.

- Conversations with industry sources indicate that the **thermal power generation** system in the DPRK is rapidly eroding. In virtually all of the large power stations, only selected boilers and turbines are operating, if any are operating at all. The (nominal) 200 MW heavy fuel oil-fired plant near the (East Coast) Sonbong refinery apparently did not operate at all in 2000, and at least three other 100 MW plants also did not operate. Those plants that do operate are reportedly plagued by problems with "air heaters"—devices that extract heat from exhaust gases to heat incoming combustion air. These air heaters have in most plants been degraded to the point of inoperability by acid gases from the combustion of high sulfur fuels such as heavy oil and used tires[105]. The result is reportedly a considerable decrease in plant efficiency, quite possibly greater than the decrease in efficiency (from 28 percent in 1990 to 23 percent in 2000, before accounting for plant own use) that we have assumed. Further, boiler tubes in many power plants have been degraded from the outside by acid gases from high-sulfur fuels, and from the inside by inadequately-treated, or untreated boiler feed waters. The lack of spare boiler tubes—and in many cases it may be that boiler tubes to fit these generators, which were built in the 1950s and 1960s, are not available—means that it is very difficult to repair the boiler tube degradation. Two power plants, however, have been added to the roster of thermal generators that we previously knew about. A 60 MW plant built for operation on heavy fuel oil is located near the small West Coast refinery described above. This power plant only operates when crude oil is processed by the associated small refinery. A diesel engine-type plant with capacity totaling 9.8 MW was recently installed and operated for much of 2000 at Songlim, in association with a steel plant there. This plant generally seems to have been fueled with heavy fuel oil. In total, we estimate that less than 800 MW of thermal capacity were operable as of 2000, though it is possible that some other units were technically operable, but did not operate due to lack of fuel. For those power plants that are operable, we estimate an average capacity factor in the range of 50 percent or less, due to maintenance problems and lack of fuel.

- As a consequence of the difficulties with thermal power plants, **hydroelectric plants** have shouldered the burden of power generation in the DPRK. Information from industry sources indicate that any difficulties associated with the 1995/1996 flood damage to the shared power stations (China/DPRK) along the Chinese border has been repaired, and those plants are operating normally. Normally, however, apparently means that those plants—about 700 MW of capacity each for China and for the DPRK—are used largely in a peaking mode to conserve river water, and operate at full capacity only during the rainy mid-July to mid-August period. We have thus assumed an overall capacity factor of 17.5 percent for these units. Other hydroelectric facilities in the DPRK may in fact be operated in a similar manner, and it is clear that the country as a whole has far less power in the dry winter than at other times of the year. We have assumed that of the approximately 4000 MW of other hydroelectric plants, 80 percent of capacity is operable, and those operable hydro plants had a capacity factor in 2000 (a low water year) equaling 70 percent of the capacity factor assumed for 1996, or about 34 percent overall. This could, in fact, prove an over-estimate.

- A major "Youth Dam" including a tunnel system for carrying water, has recently been completed, but its hydroelectric capacity, if any, is unclear. Also underway, at the time of

[105] Oxford Recycling Inc. (http://www.oxfordrecycling.com/product.html#5, visited 6/8/02) lists a sulfur content of 1.3 percent for fuel from shredded tires.

the most recent Nautilus visit to the DPRK, was a scheme to dam the Taedong River to provide irrigation water to rice fields on the Southwest Coast of the DPRK without the need to pump water from the Nampo barrage area. It is not clear to the authors whether the latter project has or is expected to have associated hydroelectric capacity, or whether the "Youth Dam" and the Taedong water diversion project are related.

- The above assumptions as to electricity generation imply a gross output of about 12.6 terawatt-hours in 2000. Chinese customs statistics cite export of 22.7 GWh to China from the DPRK, apparently in addition to the shared output of the plants on the border rivers[106].
- We have assumed, based on reports of the continuing erosion of the transmission and distribution (T&D) grid, that T&D losses were 15 percent higher in 2000 than in 1996, totaling over 26 percent of net generation. Although "own use" at coal-fired power plants was assumed to remain at 9 percent of gross generation, we assumed that additional "emergency losses" decreased net output at coal-fired power plants by another 10 percent.

3.4. Presentation of Estimated Year 2000 DPRK Energy Balance, and Discussion of Results

In this section we present our estimated DPRK energy balance for 2000. We start with a presentation of results for all fuels, then focus on the supply of and demand for electricity, a fuel of particular concern in the DPRK for a number of economic, technical, and political reasons. As with our 1990 and 1996 balances, this picture of the DPRK energy sector in 2000 was pieced together from information from many different sources, with many assumptions made to fill in the gaps in data. In so doing, we have attempted, however, to make the balance as internally consistent as possible. Although the balance is doubtless in error in many areas, we hope that it will provide a good starting point for those studying and discussing the current state of the energy sector in the DPRK, and would welcome any additional information or that reviewers of this document can provide. Additional results of our estimates of year 2000 energy supply and demand in the DPRK can be found in Attachments 1 and 2 to this Report.

3.4.1. Supply and demand for energy in the DPRK in 2000

Table 3-1 presents a summary version of our estimated 2000 energy balance for the DPRK. A more detailed version of this balance is presented as Table 3-2, and a detailed balance that focuses on the supply of and demand for refined petroleum products is shown as Table 3-3. Figure 3-1 shows the demand for energy by fuel in 2000. Here the largest difference between 1996 and 2000 is a pronounced (and continuing) increase in the fraction of the total DPRK energy budget supplied by wood and biomass (32 percent in 1996 vs. 42 percent in 2000), with a corresponding decrease in the fractions of the budget accounted for by other fuels, particularly coal products.

Figure 3-2 shows the breakdown of overall energy use by sector in 2000. This figure shows a continuation of the trend of 1990 to 1996, in that the residential sector uses an even larger share (now more than half) of the overall energy budget by 2000, while the industrial

[106] Apparently the shared hydro facilities on the Tumen and Yalu rivers have turbine sets dedicated to and operated by the DPRK, and turbine sets dedicated to and operated by China. The two sets of turbines are operated at different frequencies. The water resource appears, however, to be jointly managed, so that the two sets of turbines operate with the same capacity factor.

sector share shrinks to under a quarter of the total. This change is the combined result of continued reduction in fuel demand in the industrial sector, relatively constant use of wood and other biomass fuels in the residential sector, and reductions in the use of other residential fuels (notably coal and electricity) that are not as severe as the reductions experienced in the industrial sector. Figure 3-3 shows the pattern of final fuels demand by fuel. Figures 3-4 and 3-5 show the pattern of demand for coal and for oil products in 2000, respectively.

Table 3-1: Summary Estimated Supply/Demand Balance for the DPRK in 2000

UNITS: PETAJOULES (PJ)	COAL & COKE	CRUDE OIL	REF. PROD	HYDRO/ NUCL.	WOOD/ BIOMASS	CHAR-COAL	ELEC.	**TOTAL**
ENERGY SUPPLY	386	25	40	35	359	-	(0)	844
Domestic Production	384	-	-	35	332	-	-	752
Imports	9	25	43	-	27	-	-	104
Exports	8	-	3	-	-	-	0	11
Stock Changes	-	-	-	-	-	-	-	-
ENERGY TRANSF.	(55)	(25)	6	(35)	(8)	3	29	(85)
Electricity Generation	(32)	-	(16)	(35)	-	-	45	(38)
Petroleum Refining	-	(25)	24	-	-	-	(0)	(1)
Coal Prod./Prep.	(19)	-	-	-	-	-	(3)	(21)
Charcoal Production	-	-	-	-	(8)	3	-	(5)
Own Use	-	-	(1)	-	-	-	(2)	(3)
Losses	(5)	-	-	-	-	-	(12)	(16)
FUELS FOR FINAL CONS.	331	-	46	-	351	3	29	759
ENERGY DEMAND	331	-	46	-	351	3	29	759
INDUSTRIAL	153	-	12	-	0	-	13	177
TRANSPORT	-	-	8	-	0	-	3	11
RESIDENTIAL	108	-	3	-	280	3	3	396
AGRICULTURAL	9	-	2	-	40	-	2	53
FISHERIES	-	-	1	-	-	-	0	1
MILITARY	38	-	17	-	-	-	5	59
PUBLIC/COMML	21	-	-	-	-	-	4	25
NON-SPECIFIED			-					-
NON-ENERGY	2		5		29			36
Elect. Gen. (Gr. TWhe)*	2.64	-	0.15	9.85	-	-	-	12.64

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-2: Detailed Estimated Supply/Demand Balance for the DPRK in 2000

UNITS: TERAJOULES (TJ)	COAL & COKE	CRUDE OIL	REFINED PROD.	HYDRO/ NUCLEAR	WOOD/ BIOMASS	CHARCOAL	ELECTRICITY	**TOTAL**
ENERGY SUPPLY	385,716	24,796	39,996	35,449	358,572	-	(82)	844,448
Domestic Production	384,185	-		35,449	331,906			751,540
Imports	9,318	24,796	43,005		26,667			103,786
Exports	7,788		3,009				82	10,878
Inputs to International Marine Bunkers								-
Stock Changes			-					-
ENERGY TRANSFORMATION	(54,984)	(24,796)	5,891	(35,449)	(7,680)	2,534	29,301	(85,183)
Electricity Generation	(31,593)		(16,278)	(35,449)			45,490	(37,830)
Petroleum Refining		(24,796)	23,577				(147)	(1,366)
Coal Production/Preparation	(18,627)						(2,523)	(21,149)
Charcoal Production					(7,680)	2,534		(5,146)
Coke Production								-
Other Transformation								-
Own Use			(1,408)				(1,955)	(3,363)
Losses	(4,764)						(11,565)	(16,329)
FUELS FOR FINAL CONSUMPTION	330,732	-	45,887	-	350,892	2,534	29,219	759,265
ENERGY DEMAND	330,760	-	45,883	-	350,920	2,539	29,216	759,318
INDUSTRIAL SECTOR	152,875	-	11,652	-	327	-	12,612	177,465
Iron and Steel	77,301						4,141	81,442
Cement	29,531		6,490				1,867	37,889
Fertilizers	2,906						2,288	5,194
Other Chemicals	2,287		-				1,350	3,637
Pulp and Paper	822						190	1,012
Other Metals	4,842						842	5,684
Other Minerals	-		4,274				134	4,408
Textiles	5,998						510	6,507
Building Materials	21,024						64	21,088
Non-specified Industry	8,165		888		327		1,225	10,604
TRANSPORT SECTOR	-	-	7,717	-	489	-	3,160	11,365
Road			6,044		489			6,533
Rail	-		585				3,160	3,745
Water	-		439					439
Air			650					650
Non-Specified			-				-	-
RESIDENTIAL SECTOR	107,645	-	2,582	-	280,316	2,539	2,788	395,870
Urban	58,127		1,905			2,539	2,463	65,034
Rural	49,517		677		280,316		325	330,836
AGRICULTURAL SECTOR	8,775	-	1,763	-	40,455	-	2,500	53,493
Field Operations			1,048				882	1,930
Processing/Other	8,775		716		40,455		1,618	51,564
FISHERIES SECTOR	-	-	808	-	-	-	42	849
Large Ships	-		725					725
Processing/Other	-		83				42	125
MILITARY SECTOR	38,290	-	16,606	-	-	-	4,518	59,414
Trucks and other Transport			5,894					5,894
Armaments			2,353					2,353
Air Force			1,703					1,703
Naval Forces			6,555					6,555
Military Manufacturing	710		-				38	748
Buildings and Other	37,580		100				4,480	42,160
PUBLIC/COMMERCIAL SECTORS	21,249		-		-		3,597	24,846
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE	1,926		4,755		29,333			36,015
Electricity Gen. (Gross TWhe)*	2.64		0.15	9.85				12.64

**Note: Gross terawatt-hours for coal fired plants includes output for plants co-fired with coal and heavy fuel oil.*

Table 3-3: Detailed Estimated Refined Products Supply/Demand Balance for the DPRK in 2000

UNITS: TERAJOULES (TJ)	CRUDE OIL	GASOLINE	DIESEL	HEAVY OIL	KEROSENE & JET FUEL	LPG, REF. FUEL, NON-E.	AVIATION GAS	**TOTAL**
ENERGY SUPPLY	24,796	6,276	9,138	18,751	2,421	3,411	-	64,792
Domestic Production	-							-
Imports	24,796	6,276	9,138	21,576	2,421	3,594		67,801
Exports				2,825		183		3,009
Inputs to International Marine Bunkers								-
Stock Changes		-		-	-			-
ENERGY TRANSFORMATION	(24,796)	4,433	5,240	(7,128)	1,183	1,577	585	(18,905)
Electricity Generation				(15,407)		(870)		(16,278)
Petroleum Refining	(24,796)	4,433	5,240	8,279	1,183	3,856	585	(1,219)
Coal Production/Preparation								-
Charcoal Production								-
Coke Production								-
Other Transformation								-
Own Use						(1,408)		(1,408)
Losses								-
FUELS FOR FINAL CONSUMPTION	-	10,709	14,378	11,623	3,604	4,988	585	45,887
ENERGY DEMAND	-	10,678	14,379	11,630	3,622	4,988	585	45,883
INDUSTRIAL SECTOR	-	-	643	11,009	-	-	-	11,652
Iron and Steel								-
Cement				6,490				6,490
Fertilizers								-
Other Chemicals								-
Pulp and Paper								-
Other Metals								-
Other Minerals				4,274				4,274
Textiles								-
Building Materials								
Non-specified Industry			643	245				888
TRANSPORT SECTOR	-	3,628	3,220	219	300	-	350	7,717
Road		3,628	2,416					6,044
Rail			585					585
Water			219	219				439
Air					300		350	650
Non-Specified			-					-
RESIDENTIAL SECTOR	-	-	-	-	2,349	233	-	2,582
Urban					1,672	233		1,905
Rural					677			677
AGRICULTURAL SECTOR	-	-	1,763	-	-	-	-	1,763
Field Operations			1,048					1,048
Processing/Other			716					716
FISHERIES SECTOR	-	-	445	362	-	-	-	808
Large Ships			362	362				725
Processing/Other			83			-		83
MILITARY SECTOR	-	7,050	8,307	39	974	-	235	16,606
Trucks and other Transport		5,797	97					5,894
Armaments		404	1,949					2,353
Air Force		494			974		235	1,703
Naval Forces		355	6,161	39				6,555
Military Manufacturing								-
Buildings and Other			100					100
PUBLIC/COMMERCIAL SECTORS			-					-
NON-SPECIFIED/OTHER SECTORS			-					-
NON-ENERGY USE						4,755		4,755

Figure 3-1:

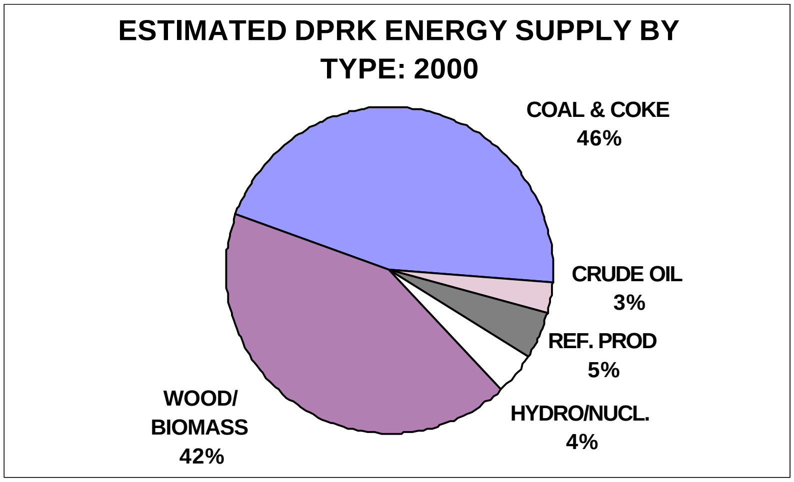


Figure 3-2:

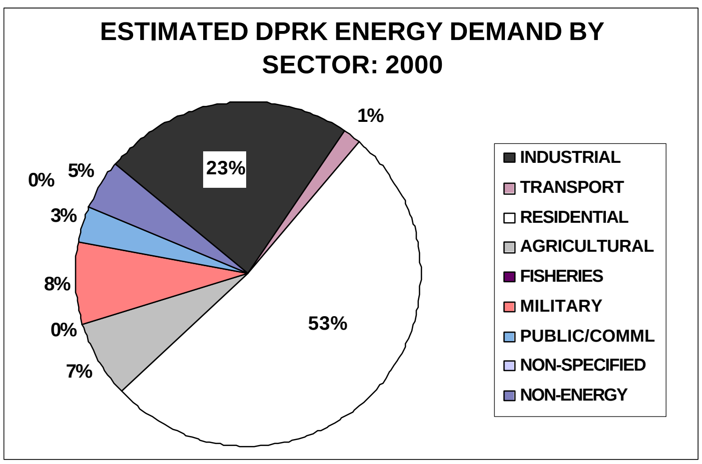


Figure 3-3:

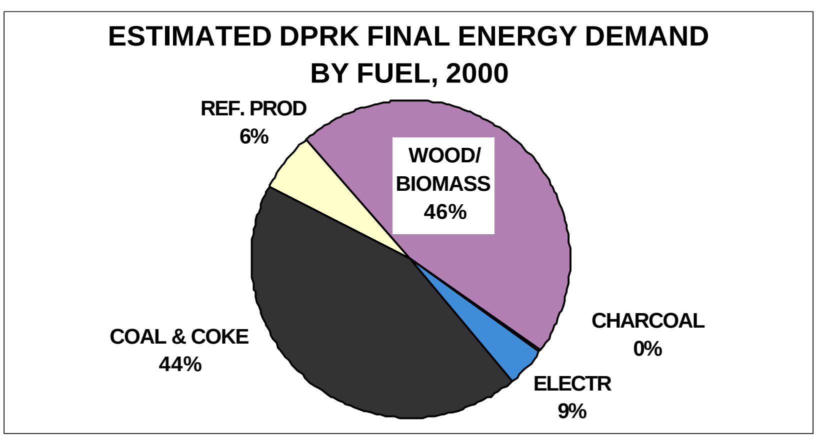


Figure 3-4:

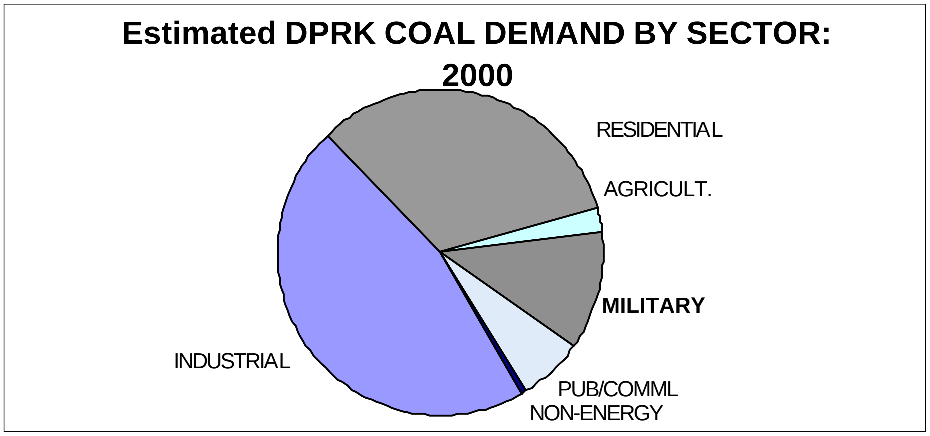


Figure 3-5:

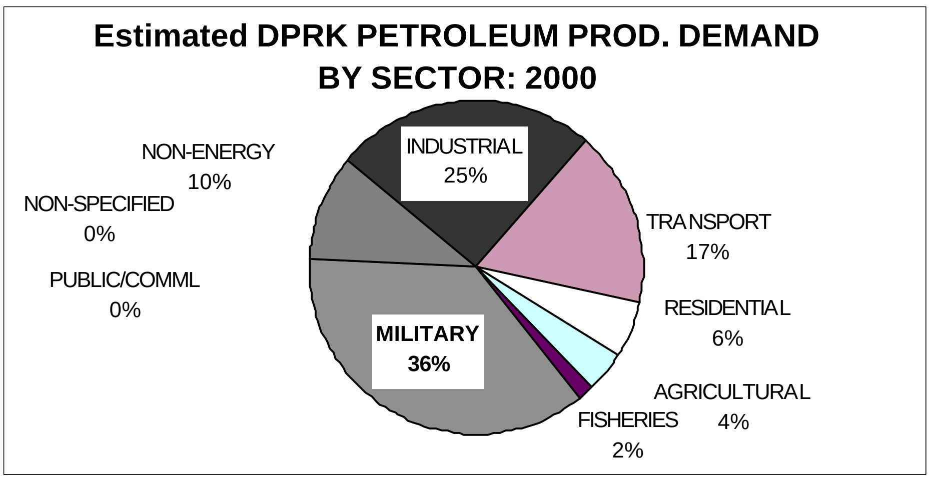


Table 3-4 shows the structure of demand for three key oil product categories—diesel oil, gasoline, and kerosene/jet fuel/LPG—in 1990, 1996, and 2000. Of these three categories, gasoline use has decreased by the largest percentage between 1996 and 2000. Kerosene use increased somewhat in the residential sector due to the reduction in electricity use for lighting (although, based on our experiences in the DPRK, some or much of the fuel used in oil lamps is diesel fuel rather than kerosene). Even more than in 1996, 2000 gasoline use is dominated by the Military sector. Table 3-5 summarizes heavy fuel oil demand in 1990, 1006, and 2000.

Table 3-4: Demand for Non-HFO Refined Petroleum Products by Sector—1990, 1996, and 2000

Demand Summary for Other Refined Products: Terajoules

	DIESEL OIL			GASOLINE			KERO/JET FUEL/LPG		
SECTOR	**1990**	**1996**	**2000**	**1990**	**1996**	**2000**	**1990**	**1996**	**2000**
INDUSTRIAL	3,500	809	643	-	-	-	-	-	-
TRANSPORT	11,880	3,715	3,220	22,783	10,013	3,628	399	320	300
RESIDENTIAL	-	-	-	-	-	-	7,300	2,128	2,582
AGRICULTURAL	5,005	1,502	1,763	-	-	-	-	-	-
FISHERIES	1,073	537	445	-	-	-	-	-	-
MILITARY	8,820	7,206	8,307	7,794	6,822	7,050	1,798	1,348	974
NON-SPECIFIED/OTHER	2,000	-	-	-	-	-	3,700	-	-
TOTAL	32,279	13,768	14,379	30,578	16,836	10,678	13,197	3,796	3,855
INDUSTRIAL	11%	6%	4%	0%	0%	0%	0%	0%	0%
TRANSPORT	37%	27%	22%	75%	59%	34%	3%	8%	8%
RESIDENTIAL	0%	0%	0%	0%	0%	0%	55%	56%	67%
AGRICULTURAL	16%	11%	12%	0%	0%	0%	0%	0%	0%
FISHERIES	3%	4%	3%	0%	0%	0%	0%	0%	0%
MILITARY	27%	52%	58%	25%	41%	66%	14%	36%	25%
NON-SPECIFIED/OTHER	6%	0%	0%	0%	0%	0%	28%	0%	0%
TOTAL	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 3-5: Demand for and Supply of Heavy Fuel Oil—1990, 1996, and 2000

HFO Demand Summary: Petajoules (PJ)

	YEAR		
CONSUMER	**1990**	**1996**	**2000**
OIL-ELECT.	15.6	11.7	2.6
COAL-ELECT	6.0	12.9	12.8
INDUSTRY	21.6	7.7	11.0
SHIPS	1.5	0.8	0.6
STORAGE	-	7.5	-
TOTAL	**44.8**	**40.5**	**27.0**
OIL-ELECT.	35%	29%	10%
COAL-ELECT	13%	32%	47%
INDUSTRY	48%	19%	41%
SHIPS	3%	2%	2%
STORAGE	0%	18%	0%
TOTAL	100%	100%	100%

3.4.2. Supply and demand for electricity in 2000

Table 3-6 and Figure 3-6 show the estimated structure of electricity supply in the DPRK in 1990/1996 (for comparison) and in 2000, broken down as generation in hydroelectric plants, generation fueled with HFO (independent of whether the plant was designed to use oil), and thermal plants fueled with coal. Note that this figure displays gross generation: some of the electricity produced is used in the power plant itself, some is lost as a result of "emergencies", and more is lost during transmission and distribution. The total estimated supply of electricity (including electricity exports to China) decreased substantially between 1990 (46 terawatt-hours, or TWh[107]) and 1996 (22 TWh), and fell still further (by our estimate) by 2000 (to 12.6 TWh). This estimate for 2000 is considerably lower than other estimates[108], but is in our opinion more likely to be close to actual 2000 generation, as it is built up based on information as to the status of generation facilities. Reflected in Figure 3-6 is the significant drop in hydroelectric output as a result of damage to hydroelectric impoundments (and perhaps generating equipment) from the floods of 1995 and 1996, and a considerable drop in thermal plant output between 1996 and 2000[109].

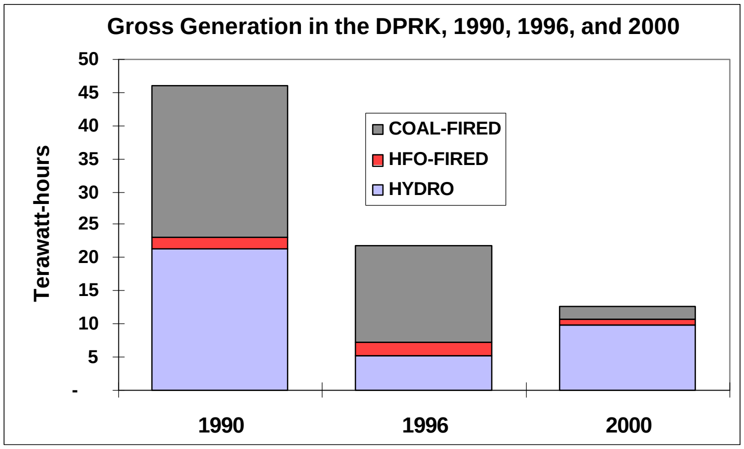
Table 3-6:

Supply Summary for Electricity: Terawatt-hours of Gross Generation

	YEAR		
GENERATION	**1990**	**1996**	**2000**
HYDRO	21.3	5.3	9.8
HFO-FIRED	1.7	1.9	0.9
COAL-FIRED	23.0	14.7	1.9
TOTAL	46	22	13
HYDRO	46%	24%	78%
HFO-FIRED	4%	9%	7%
COAL-FIRED	50%	67%	15%
TOTAL	100%	100%	100%

[107] One terawatt-hour is equal to 3600 terajoules, 3.6 million gigajoules, or one billion kilowatt-hours (kWh).
[108] For example, data provided to Nautilus by KEEI (and based on data from the ROK National Statistics Office) shows 19.2 TWh of total generation in 2000, of which 10.2 TWh (slightly less than our estimate) is hydro generation, and 9.2 TWh (about three times our estimate) is thermal generation.
[109] It is clear that the degradation of the electricity sector has not gone un-noticed by DPRK authorities. Reports in the media and elsewhere indicate that the DPRK is actively seeking both low-cost and longer term (for example, contacts on T&D infrastructure refurbishment with the Swiss multinational ABB) "fixes" to its problems. How these upgrades will be paid for remains unclear.

Figure 3-6: Estimated Sources of Electricity Supply: 1990, 1996, and 2000



The estimated structure of demand for electricity is shown in Figure 3-7 for 1990, 1996, and 2000. The fractions of demand by sector are shown in Figure 3-8 . Industrial demand for electricity accounted for a slightly larger fraction of the total in 2000 than it did in 1996, with the residential share declining (as a result of lack of availability of electricity in many areas) and shares used by agriculture (for example, irrigation and crop processing, a national priority) and the military increasing.

Figure 3-7: DPRK Electricity Consumption by Sector: 1990, 1996, and 2000

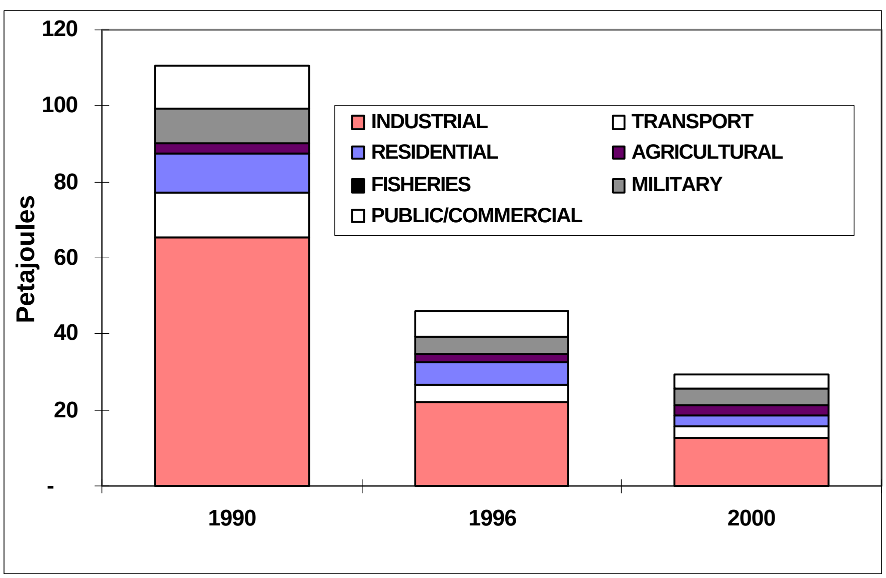
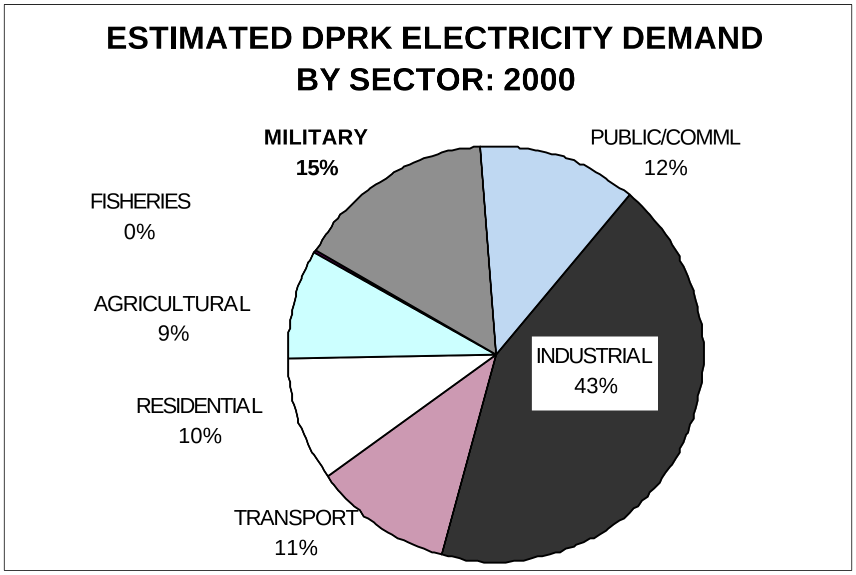


Figure 3-8:



4. Future Prospects and Suggestions for DPRK Energy Sector

4.1. Introduction

Despite a few outward signs (and the key word here is "outward") of economic recovery in recent years—including more activity in the capital and a population that looks, in general, better nourished (to at least some visitors)—it is clear, if our estimates are close to correct, that the DPRK energy sector is a long way from good health. What does the near- and medium-term future hold for the DPRK, and what can be done by the international community in general, and the ROK in particular, to make the lives of DPRK citizens somewhat less burdensome? This final chapter of this report examines these questions, and provides some ideas for initiatives that could assist the DPRK in building a sustainable energy sector.

4.2. The DPRK Under a Medium-Term "Rebuilding" Pathway

Below we describe, in a very qualitative way, what a medium-term "Rebuilding" path might look like for the DPRK economy and, by extension, for the DPRK energy sector. This qualitative sketch is a first step to the estimation of the quantitative attributes of such a path—what the path might mean in terms of future terajoules, tonnes of coal, and megawatts.

First and foremost, the "Rebuilding" pathway implicitly assumes a major breakthrough in relations with the ROK (and probably the United States as well), resulting in some investment in the industrial and energy infrastructure in the DPRK from outside the country, and much increased foreign development aid. The "Rebuilding" path also assumes, however, that the DPRK government essentially maintains its integrity. If the current DPRK government loses power, rapid reunification of North and South Korea may result, which probably means very large, very fast changes for the DPRK energy sector, providing that the unified Korea can obtain internal and external financing for infrastructure reconstruction in the North.

A “**Rebuilding**” pathway for the DPRK would likely be built upon the following assumptions:

- With some political and economic opening, coupled with increased foreign aid, the DPRK economy starts to rebuild (for example, in 2003).
- Industrial production increases, particularly in the lighter industries; and there is increased demand for transport.
- There is an increase in household energy use, with trends toward using more electricity, LPG, and kerosene in homes.
- There is a considerable increase in commercial sector activity, and a relatively small increase in military sector energy use.
- Refurbishment of electric transmission and distribution infrastructure takes place, coupled with refurbishment of existing hydro plants, building of new hydro capacity, the re-starting and expansion of the DPRK's east coast refinery, and partial retirement of coal-fired electricity generating capacity.
- Modest improvements in energy efficiency take place.

This pathway, or one very much like it, may in fact be one of the only ways that DPRK infrastructure can recover enough to use even some of the power from the nuclear reactors being built by KEDO within the DPRK. There is at present no way to use the reactors, when they are complete, within the existing DPRK grid[110], so interties to other countries must be constructed, and preferably, from a political and practical perspective, the DPRK grid must be totally rebuilt as well. The disposition of the KEDO reactors is therefore both a huge problem that could lead to poor relations between the DPRK and the outside for years to come, or, if handled correctly, a huge opportunity for building of economic links (and better relations) between the countries of the region.

4.3. Internal Policy and Legal Reforms to Stimulate and Sustain Energy Sector Rebuilding in the DPRK

There are a number of areas in which DPRK policies must be revised if the DPRK energy sector is to be rebuilt within a more open economy. ROK and other nations could assist in the process of learning and phasing in the types of reforms that will be necessary. Some of the areas in which policy reform is called for are described briefly below.

---

[110] Nuclear safety concerns (back-up power for coolant pumps and controls) and the attributes of a large-capacity nuclear unit operating in a small power grid (the DPRK grid is far below the minimum size to support the KEDO reactors) are key reasons why these reactors cannot operate under current conditions. See D. Von Hippel et al (2001), "Modernizing the US-DPRK Agreed Framework: The Energy Imperative" as referenced earlier in this report.

4.3.1. Reform of energy pricing practices and the physical infrastructure to implement them

Hand in hand with rebuilding of energy supply infrastructure should go the rebuilding of end-use equipment, but accomplishing the former in a cost-effective manner is in large part dependent on making sure that new end-use equipment is purchased and operated with an eye toward efficiency. The economic levers of prices, in a market economy, are important tools for helping to make sure that energy is used wisely.

Before adopting market style pricing of energy commodities, ***the modification of existing incentives facing plant managers and relevant officials*** to encourage more efficient use of energy. Despite some problems, quota management and administrative measures were key to China's success in eliminating many of the worst energy inefficiencies in its industrial sector, and in stimulating adoption of relatively more advanced techniques and technologies. Although inappropriate to a market economy, a well-designed program of administrative measures would effectively utilize the strengths of North Korea's current form of government, and would be a first step toward a more efficient energy economy.

Reforming energy pricing is a longer-term goal. Before market forces of any kind can help to spur the implementation of energy efficiency measures (or choices of efficient, rather than the cheapest, equipment on the supply side), the prices for energy products in the DPRK must be adjusted towards their actual costs of production. This adjustment must include products that are currently not priced at all. Pricing of some energy products, particularly electricity, will require the implementation of metering and billing systems. To be effective, parallel reforms that sensitize local decision-makers to prices (that is, that allow them to benefit from cost savings) must be implemented.

One way to modify existing disincentives for energy efficiency is to ***promote changes in physical infrastructure that will facilitate energy decision-making.*** In previous reports (and in brief below), we have discussed some of the types of energy-using equipment and other infrastructure in the DPRK that could be targeted for replacement or rehabilitation. What has been emphasized relatively less, but is at least as important, is the need to invest in equipment that allows flows of energy to be controlled and quantified adequately. Such equipment includes electricity, heat, and hot water meters; steam and process control valves and shunts; and dimmers and other equipment for controlling lighting. Applications for such equipment exist throughout the residential, commercial/public/military, and industrial sectors. Without such equipment--which typically is inexpensive and relatively easy to install and operate--any attempt to institute price signals in energy markets, or even to reward reduced energy use in other ways, will be futile, as end-users will lack the ability to control energy flows, the quantitative feedback that tells them whether efforts to reduce energy use have succeeded, or—worst of all—both.

4.3.2. Training for energy sector actors

Recovery of the DPRK economy, and modification of the DPRK’s energy and industrial infrastructure, will require that a wide spectrum of energy sector actors—from analysts in planning institutions to building maintenance personnel—receive training on topics varying from long-range energy planning (as noted above) to operation and maintenance of commercial boilers. Here, regional cooperation will be helpful in making experienced personnel available to train their counterparts in the DPRK.

In particular, if energy efficiency and renewable energy are to be successful in the DPRK–and these may be the areas where, given stated interest on the part of the DPRK government, and the potential small unit size of assistance efforts, it will be possible to start energy cooperation with the DPRK–it will be necessary to ***provide specific information and training to local actors.*** Training of a very specific and practical nature must be provided to personnel at the local level. Examples here are factory energy plant managers, boiler operators in residential and commercial buildings, power plant and heating system operators, and new job classifications such as energy-efficiency equipment installers and energy auditors. The departure of Soviet/Russian assistance left a vacuum of technical expertise that, according to some observers, very much persists to this day. The sort of training described above is therefore both badly needed and a necessary complement (or, more probably, precondition) for any other type of technical assistance to the DPRK energy sector.

4.3.3. Strengthening regulatory agencies and educational/research institutions in the DPRK

There is a definite need to strengthen a variety of North Korea's government institutions through a combination of provision of information, persuasion of leaders, training of personnel, and supplying institutions with needed equipment. Many of these tasks have been started (or at least attempted) by initiatives of the United Nations Development Programme (UNDP) and other ongoing programs.

One general area in which DPRK institutions could be strengthened is in their ability to ***implement standards, and enforce them.*** DPRK officials have made general statements about their support for energy efficiency and environmental protection. The next step is to codify these in terms of quantitative standards for the efficiency of new appliances and equipment, as well as 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, it will be necessary to create the capability to enforce them by recruiting and training enforcement personnel and supplying them with the tools necessary to do their job (testing equipment and adequately equipped labs, for example) and the high-level administrative support needed for credible implementation of sanctions.

Standards for specific energy consumption (for example, the amount of energy needed to produce a unit of physical output) have long been used in China to gauge performance of and within industrial and other enterprises. Issued nationally, and often tailored to conditions specific to individual enterprises, these standards have been used to measure progress in improving efficiency, and have formed the basis of a system of financial and other awards. It is, in effect, a system of performance evaluation that parallels that based on output levels and product quality. This system is losing its effectiveness as China's transition to a market-oriented economy progresses and the central planning apparatus weakens, but it may still be quite appropriate for North Korea at this time.

There is not as yet in the DPRK, 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 an institution, which could be modeled on existing institutions like the Beijing Energy Conservation Center and a similar Center in Russia. The Center in China was established jointly with the Battelle Pacific Northwest Laboratory and the Lawrence Berkeley National Laboratory (both U.S. government-sponsored organizations with extensive experience in energy demand issues), and the Center in Russia was founded with Battelle[116]. It is possible that the Center for the Rational Use of Energy (CRUE), formed during the early 1990s within the existing DPRK Institute of Thermal Engineering under a UNDP project, could be strengthened through a combination of North Korean and extramural 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.

4.3.4. Involving the private sector in investments and technology transfer

Much of the money and other assistance necessary to help the DPRK toward recovery will have to come from the more flexible and fast-moving private sector. If substantial private-sector financing for DPRK projects is to be forthcoming, it is likely that inducements and guarantees—possibly supplied by other governments of the region—will be necessary in order to mediate, at least initially, the risk of dealing with the DPRK.

One way that the governments of the region, including the DPRK government, and governments of other countries with an interest in what happens in Korea (including the United States) can help in this regard is to *promote joint ventures and licensing agreements*. The government of the DPRK, and other interested parties, should promote joint ventures and licensing agreements between DPRK concerns (governmental or otherwise) and foreign firms with energy-efficient technologies to produce. Compact fluorescent light bulb factories are a commonly cited example of potential energy technology transfers[117]. 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 have already been introduced to China through commercial channels are being or will be manufactured there.

Wind turbine-generators are another intriguing possibility, given the apparent success of such ventures in former East-bloc nations[118] and the North Koreans' historical emphasis on machinery manufacture. Foreign firms that have successfully transferred efficient and renewable technologies to China, Russia, and Eastern European nations represent a valuable repository of experience that could be applied to similar efforts in North Korea. Depending on how fast the Tumen River Economic Development Zone develops (infrastructure in the area is not yet adequate to support major industry), this area could be the location most acceptable to the DPRK for the first such ventures. It is likely that the first few foreign companies to participate in joint ventures in the DPRK will require guarantees not only from the DPRK government, but also from their own government or another industrialized-nation or a multilateral donor.

Before any of these types of ventures can be initiated, however the DPRK will have to implement, and show the international community that it is adequately enforcing laws to protect the intellectual property and investments of foreign companies doing business in the DPRK. A description of all of the areas in which such laws are required, and the reasons why they are needed, is, however, beyond the scope of this report.

4.4. Potential for International Cooperation to Assist in the Redevelopment of the DPRK Energy Sector

Key economic resources for the DPRK include a large, well-trained, disciplined, and eager work force, an effective system for dissemination of technologies, the ability to rapidly mount massive public works projects by mobilizing military and other labor, and extensive reserves of minerals. What the DPRK lacks are modern tools and manufacturing methods, fuel, arable land (though the land it does have might be just sufficient to feed its population with some improvements in agricultural methods), and above all, capital and the means to generate it (other than weapons sales). As a consequence, given the energy sector problems outlined above, a coordinated program of assistance from the ROK, the United States, and other countries that builds upon these skills will be needed. Providing key assistance in a timely manner will enhance security in Northeast Asia, accelerate the process of North Korean rapprochement, and help to position the countries and firms as major suppliers for the DPRK rebuilding process.

The nature of the DPRK's energy sector problems, however, mean that an approach that focuses on one or several massive projects—such as a single large power plant—will not work. A multi-pronged approach on a number of fronts is required, with a large suite of coordinated, smaller, incremental projects addressing needs in a variety of areas. Installing a large power plant in the DPRK without addressing problems of fuel supply, end-use efficiency, and electricity transmission and distribution, and without helping the DPRK to develop the means to peacefully earn the money to pay for the plant plus its operating expenses, is putting the cart before the horse. Providing a power plant with no fuel supply, or a power plant with fuel supply but no workable grid, or fuel supply and an upgraded grid but no power plant, or even a power plant with fuel supply and an upgraded grid but no efficient end use equipment (or no end use equipment at all) with which to use the electricity, are neither cost-effective nor even feasible options in the DPRK. A coordinated approach is necessary.

Below, we identify priority areas where we see DPRK energy sector assistance as both necessary and in the best interests of all parties. All of these interventions would put foreign (US, ROK, or other) engineers and other program staff in direct contact with their DPRK counterparts and with DPRK energy end-users. In our own experience working on the ground in the DPRK, visitors working hard to help and to teach North Koreans has great effectiveness in breaking down barriers between our peoples. Actions speak louder than words or missiles in negotiating with North Korea.

4.4.1. Provide technical and institutional assistance in implementing energy efficiency measures

Focusing in particular on energy efficiency, regional cooperation would be useful to help the DPRK to:

- ***Provide the DPRK with access to energy-efficient products, materials and parts***. Since these items will probably, at least initially, be imported, this will entail a loosening of restrictions on imports. China, already one of North Korea's largest trading partners, would be a good source of efficient technologies and equipment that may be more easily absorbed (and more affordable) than those available from already developed countries. China has been a major energy supplier to North Korea in the past, and may have an interest not only in marketing equipment, but in reducing North Korea's dependence on energy imports.
- ***Pursue sector-based implementation of energy efficiency measures.*** One point made forcefully by studies of East European economies “in transition” (Lee Schipper and Eric Martinot) is the need to pursue energy efficiency opportunities on a sector-by-sector basis, as opposed to through an overarching "Least Cost Planning"-style of analysis as has been

practiced for electric and gas utility service areas[111]. It is people at the sectoral level who must work with energy-using equipment daily to do their jobs, rather than planners in a central ministry, who are most likely to be interested in energy-efficiency opportunities.

One way to gain support for energy efficiency measures is to emphasize those that achieve multiple goals. Energy-efficient technologies can be combined with building retrofits that increase the comfort of residents, the rebuilding of factories to improve output, the renovation of power plants to cut down on forced outages, and other upgrading efforts that have little--explicitly--to do with energy efficiency. China, in the 1980s, introduced a major process improvement to the steel industry--continuous casting--primarily as an energy efficiency measure, and supported its introduction with funding from the national program of efficiency investments. In China's other energy-intensive industries, such as chemicals and cement manufacturing, measures to increase energy efficiency have typically resulted in greater output and higher quality as well, resulting in high rates of adoption.

To the ultimate users of energy efficiency measures, the relative costs per unit of energy savings of the various possible industrial process, transport, and energy supply improvements is less than meaningful--what matters is how energy efficiency opportunities stack to up to other potential uses for the investment funds that they have available (for example, investment funds allocated from the central government). In addition, it is often counterproductive to charge personnel from the typically supply-oriented energy sector with equipment decisions in end-using sectors of the economy, because they would bring with them a strong supply-side bias.

- ***Carry out demonstration projects***. The most effective way to convince decision-makers in the DPRK—both at the national and local levels—that energy efficiency measures and programs are worthwhile will be to show that they work in specific North Korean situations. Carefully designed, effective demonstrations of energy efficiency and renewable energy technologies that involve local actors as much as possible are likely to catch the interest of North Koreans. Given the good system for technology dissemination in the DPRK, this approach is likely to lead to the adoption of energy efficiency measures into the North Korean way of doing things. One word of caution here is to make sure that any demonstration projects carried out can be replicated elsewhere in the DPRK—measures unique to one or a few specific industrial plants, for example, are not likely to be widely replicated.

4.4.2. Promote better understanding of the North Korean situation in the ROK

South Koreans have a deep and natural interest in what goes on in North Korea, but have no better access to information on the DPRK than those in other countries. It will be important in particular to involve South Korean actors—to the extent allowed and desired by North and South Korea—in the types of research and training activities mentioned above. This suggestion follows partly from the proximity of the two countries, and from the considerable economic

[111] Schipper and Martinot also point out two disadvantages of least-cost planning in the context of the former Soviet Union that are probably equally relevant to North Korea. First, stable energy markets and prices (which are inputs to Least Cost Planning) do not exist as they do (for the most part) in the West, and data on energy end-uses, as noted above, as well as cost data for domestic and imported equipment, are problematic. Second, Least-cost planning is sufficiently similar to the system of planning formerly in use in the USSR (and still used in the DPRK) that it would provide a comfortable and familiar retreat for central planners, and thus could be considered a step away from, rather than towards, economic reform

support and technical know-how amount that the South can offer the North. In addition, given our premise that the two countries will reunify, we believe that the more contact officials from the two countries have, and the more they know about each other, the less painful will be the process of reunification.

4.4.3. Work to open opportunities for IPP companies to work in the DPRK

As noted above, the scale and complexity of the energy sector problems in the DPRK mean that the most reasonable way to address those problems is on a local and regional level. Though the ROK (and US, for example) governments might reasonably provide technical assistance and limited direct humanitarian aid, as well as support for international efforts, it is probably unreasonable to expect other countries to directly underwrite the renovation of DPRK infrastructure on even a county scale. What the other governments can do, however, is pave the way for companies such as Independent Power Producers (IPPs) to operate in the DPRK. In this liaison role, the governments could provide assistance to firms in identifying, negotiating with, and working with DPRK counterparts, underwrite performance guarantees, and provide low-interest financing. The governments can also help by providing North Korean counterparts with training in the economics of project evaluation and in international contract law, both of which are, as noted above, at present alien concepts in the DPRK. The goal would be to assist IPP firms in working with DPRK authorities to set up with local and regional infrastructure (for example, power plants of less than 50 MWe) using small hydro installations, wind farms, or mid-sized coal-fired plants. In most cases, infrastructure projects would need to be coupled with the initiation or re-establishment of local revenue-generating activities so that IPP services can be compensated.

4.4.4. Cooperation on technology transfer for energy efficiency, renewable energy

A number of suggestions for beginning to work with the DPRK on confidence-building measures in the realm of energy efficiency and renewable energy are listed in our 1995 report on the topic[119]. Briefly, these include:

- Provide Information and General Training in energy efficiency to High-level Government Officials
- Provide Specific Information and Training to Local Actors (such as power plant managers, industrial energy plant overseers, and building boiler operators
- Encourage and support implementation and enforcement of energy efficiency standards
- Assist in establishing a Program of Grants and Concessional Loans for energy efficiency investments to industrial organizations and others
- Encourage the modification of existing incentives that thwart energy efficiency improvements
- Assist in and encourage the reform (or establishment) of energy pricing.
- Promote and support joint ventures and licensing agreements between the DPRK and foreign firms, possibly as part of development of the Rajin-Sonbong Free Trade Zone
- Initiate a program of exchange focused around methods of and training in energy planning, including consideration of the environmental impacts of energy choices.

4.5. Key/attractive energy sector technologies and processes for energy sector redevelopment in the DPRK

4.5.1. Rebuilding of the T&D system

The need for refurbishment and/or rebuilding of the DPRK T&D system, and the types of materials and equipment that will be required, have been identified briefly earlier in this Memo. The most cost-effective approach for international and ROK assistance in this area will be to start by working with DPRK engineers to identify and prioritize a list of T&D sector improvements and investments, and to provide limited funding for pilot installations in a limited area—perhaps in the Tumen River area. Ultimately, it will be necessary to engage the World Bank as a leader in DPRK power sector refurbishment, likely with funding from the Japanese government. In the short-to-medium term, local solutions could be focused on projects that would help the DPRK earn foreign exchange in acceptable manner, such as repairing T&D infrastructure and local power plants in particular areas so that facilities such as key mines can operate.

4.5.2. Rehabilitation of power plants and other coal-using infrastructure

Rehabilitating existing thermal power plants, industrial boilers, and institutional/residential boilers will result in improved efficiency so the coal that is available goes further, will reduce pollution, and will improve reliability so that the lights and heat stay on longer. Accomplishing these upgrades will require a combination of training, materials (especially control systems), and perhaps assistance to set up and finance manufacturing concerns to mass-produce small boilers and heat-exchange components.

An initial focus, in the area of boiler technology, should be on improvements in small, medium, and district heating boilers for humanitarian end-uses such as residential heating and provision of heat and hot water for hospitals, schools, and orphanages. If possible, it would be optimal to provide such upgrades in areas of the country away from Pyongyang, those hardest hit by the DPRK's economic malaise.

The DPRK building stock, even in rural areas, tends to make extensive use of masonry and concrete, with leaky windows and doors, and minimal insulation. A program of boiler upgrades should go hand-in-hand with a program of "weatherization" (insulation, caulking, weatherstripping, and window replacement). Even minimal weatherization measures promise significant savings, with attendant reductions in coal use (making the supply go further), and local and regional pollution.

Another early focus should be on rehabilitation of boilers in key industries that could help the DPRK to "bootstrap" the civilian economy. As a specific example, the DPRK has one of the world's largest deposits of the mineral magnesite, which is used in making refractory (furnace-lining) materials. Helping to rebuild the boilers or kilns that are used to produce magnesite, along with the fuel and ore-supply chains that feed them, would bring much-needed foreign exchange into the country. We suspect that with international and ROK government participation and guidance, a private sector partner from the ROK or elsewhere could be found to assist with this type of rehabilitation, and to share in the profits of a joint-venture firm.

In the short run, it may also be useful for the international community States to provide the DPRK with coal for selected power plants (to the extent that they are operable) in areas now poorly served by the existing coal and electricity supply systems. Providing such supplies, perhaps in an agreed-upon exchange for reduced HFO deliveries, would help restore humanitarian services and assist in economic revival while other energy sector upgrades are underway, and could reduce US and KEDO exposure to high HFO prices.

4.5.3. Rehabilitation of coal supply and coal transport systems

Strengthening of the coal supply and transport systems must go hand in hand with boiler rehabilitation if the amount of useful energy available in the DPRK is to increase. Foreign coal industries—in the United States and Australia, for instance, as well as China and Russia—have significant expertise to assist with evaluating and upgrading coal mines in the DPRK, including improvements in mining technologies, evaluation of coal resources, mine ventilation systems, and (we guarantee) mine safety. Coal processing to remove ash and improve fuel value could be another focus of assistance.

In parallel with any mine upgrades, rehabilitation of the coal transport network must also take place. This involves making sure that train tracks between mines and coal users are operable, that locomotives have electricity or fuel, and that working coal cars are available. In turn, this may mean providing or helping to set up a remanufacturing facility for steel rails, providing or helping to renovate factories for rail car and locomotive parts, and other types of assistance.

4.5.4. Development of alternative sources of small-scale energy and implementation of energy-efficiency measures

The North Koreans we have worked with have expressed a keen interest in renewable energy and energy-efficiency technologies. This interest is completely consistent with both the overall DPRK philosophy of self-sufficiency and the practical necessities of providing power and energy services to local areas when national-level energy supply systems are unreliable at best. Such projects should be fast, small and cheap. Some of the key areas where the United States and partners could provide assistance are:

- Small hydro turbine-generator manufacturing: Much of the rugged topography of the DPRK is well suited to small, mini, and micro-hydroelectric development, and the DPRK government has given its blessing for local authorities to undertake hydro projects. The DPRK does manufacture some small turbine-generator sets, but it is clear that assistance would be helpful to produce more reliable and cost-efficient units, as well as to expand mass production.
- Wind power: Likewise, the dissemination of wind turbines is a both a national goal and, from our first-hand observations, a keen interest of individuals in the DPRK. The barren ridges of the interior of the country are likely to be excellent wind power sites. The DPRK-manufactured wind generators and control components that we have seen, however, are at best grossly inefficient, and more likely non-functional. Design assistance and joint venture manufacturing of wind power systems are needed. A first phase might be the manufacture of lower-technology water-pumping windmills.
- Agricultural equipment efficiency measures: Helping North Koreans to feed themselves should be a high priority. The rice harvest in the DPRK is, based on our observations in the "rice basket" of the country, a nearly completely manual process. To increase productivity,

improvements are needed in tractor design and maintenance (including spare parts manufacture) to make the diesel fuel that is used in agriculture go further. Improvements in motors and drives for electrically-driven agricultural equipment, such as rice threshers and mills, will stretch supplies of electricity.

- Residential lighting improvements: Three or four times as many households can be supplied with much higher quality light with the same amount of electricity if DPRK incandescent bulbs are replaced with compact fluorescent light bulbs (CFLs). Ultimately, joint venture manufacturing (or at least assembly) of CFLs in the DPRK could be undertaken, but until then provision of CFLs of robust quality should accompany any local power supply or T&D improvement initiative. We have found this measure to be invaluable for securing grassroots support, as it provides a direct and tangible improvement in the lives of ordinary Koreans.
- Industrial and irrigation motors: The opportunities for efficiency improvement in large electric motors and motor drive systems are estimated to be considerable. Imports of efficient motors, pumps, air compressors, and other motor-related equipment may be the first step (once power quality has been improved sufficiently), followed by assistance in setting up facilities to manufacture or assemble equipment in the DPRK. Improving the reliability and efficiency of irrigation pumps will help the DPRK move toward feeding its populace.
- Humanitarian measures: Even the best orphanages, hospitals, and schools in the DPRK are cold and bleak today. Providing on-site power, preferably with renewable energy systems, water purification equipment, and efficient lighting and other end-use devices are necessary and highly visible first steps toward meeting humanitarian needs in the DPRK.

4.5.5. Rehabilitation of rural infrastructure

The goal of a rural energy rehabilitation program would be to provide the modern energy inputs necessary to allow North Korean agriculture to recover a sustainable production level and the basic needs of the rural population to be met. The priority areas would be those for which energy shortfalls most seriously affect agricultural production, human health, and fundamental quality of life. These areas include maintenance of soil fertility, farm mechanization, irrigation and drainage, and lighting, heating, cooking, and refrigeration for households and essential public institutions such as clinics and schools.

A comprehensive rehabilitation program for rural areas would feature a combination of short to medium-term energy supplies from imports and medium to long-term capital construction and rehabilitation projects. Components of an import program would include fertilizer, tractor fuel, and electricity at levels sufficient to enable agricultural recovery in the shortest attainable time. The capital construction program would include projects necessary to achieve the sustainable rehabilitation of the North Korean rural energy sector in the medium term (approximately 5 years). It is possible to outline some of the main elements of such a program: rehabilitation of the rural electricity transmission and distribution grid, development of reliable local power generation, improving the energy efficiency of the irrigation and drainage system, modernizing fertilizer and tractor factories, and improving the transportation of agricultural inputs and products. Many of these projects have already been proposed in the context of UN-sponsored agricultural reconstruction studies.

4.5.6. Electricity grid interconnections

Although hardly either a quick fix or a short-term project, it is imperative and attractive, from the perspectives of virtually all countries in the region, to move ahead with the consideration of electricity grid interconnections involving the ROK, the DPRK, Russia, and possibly China as well. The driving force for the implementation of such interconnections, in the short-to-medium term, will be, as noted above, the need to provide a means of safely "turning on" the KEDO reactors once they are complete (in, for example, the 2007 to 2010 time frame).

4.5.7. Gas supply/demand infrastructure

Little or no gas is used in the DPRK at present. Given, however, the keen interest in Russia and the ROK in extending a gas pipeline from the vast resources of Siberia and the Russian Far East to the consumers of South Korea, it may be worthwhile to start to establish an appreciation for the benefits of gas on the part of the DPRK. Initial steps might be to build very small demonstration power plants fired, for example, with liquefied petroleum gas imported to small storage facilities, and also to use gas piped from such facilities to provide essential humanitarian services and residential fuel to a small surrounding area. If these types of small, local gas distribution systems can be established, it may be possible to build a small LNG terminal in the DPRK and, as gas consumption increases and a local pipeline network begins to coalesce, consider as a next step in energy relations between the DPRK and its neighbors, an international pipeline. As a relatively clean fuel, and one that is relatively resistant to diversion for most military purposes, it may in the long run prove worth the ROK's effort to begin the process of introducing gas as a fuel in the DPRK.

4.6. Conclusion

In this report we have provided our best estimate of DPRK energy supply and demand in the years 1990, 1996, and 2000. Despite what some observers report as a turn-around in the DPRK economy, our estimates are that the DPRK's energy infrastructure continues to erode, and on a nationwide basis, supplies of commercial fuels, and probably wood and biomass as well, are extremely tight. In addition, key infrastructure, especially in the power sector, continues to erode, with only modest improvements in isolated cases running counter to the trend. We have suggested a number of initiatives and cooperative activities that we believe, assuming the right approach and open, consistent dealings on the part of all of the nations and agencies involved, could provide a means of confidence-building while providing tangible benefits at the local level to DPRK citizens.

5. Endnotes/References

[1] Embassy of the Republic of Korea (1997), “Historical Background of the Division of the Korean Peninsula”. Part of The Unification Policy of Korea, presented as part of the ROK Embassy (Washington, DC) World-wide Web site, http://korea.emb.washington.dc.us/korea/Division.html.
[2] Document in Authors' files [HT1].
[3] United States Department of Energy Energy Information Administration (UDOE/EIA, 1996), Country Analysis Brief, North Korea. Part of USDOE/EIA World-wide Web site, WWW.eia.doe.gov/emeu/cabs/nkorea.html.
[4] Korea Foreign Trade Association (1993), Major Economic Indicators for North Korea.

[5] The Economist Intelligence Unit (1994), South Korea, North Korea No. 1 1994. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994. [box 5]

[6] Far Eastern Economic Review (1995), 1995 Asia Yearbook, North Korea.

[7] Korea Trade-Investment Promotion Agency (KOTRA) data (from http://www.kotra.or.kr/main/info/nk/eng/main.php3, visited 6/3/02) in "South/North Korea's Trend of Real (GDP) Growth Rate", which lists the Bank of Korea as a Source. Similar growth in the North Korean "GNI" was also cited in data provided to Nautilus by the Korea Energy Economics Institute.

[8] U.S. Bureau of the Census (1995a), The Collapse of Soviet and Russian Trade with the DPRK, 1989-1993: Impacts and Implications. Prepared by N. Eberstadt, M. Rubin, and A. Tretyakova, Eurasia Branch, International Programs Center, Population Division, U.S. Bureau of the Census, Washington, D.C., USA. March 9, 1995.

[9] U.S. Bureau of the Census (1995b), China's Trade with the DPRK, 1990-1994: Pyongyang's Thrifty New Patron. North Korea Trade Project Memorandum, International Programs Center, Population Division, U.S. Bureau of the Census, Washington, D.C., USA. May, 1995.

[10] United States Department of Energy Energy Information Administration (UDOE/EIA, 1996), Country Analysis Brief, North Korea. Part of USDOE/EIA World-wide Web site, WWW.eia.doe.gov/emeu/cabs/nkorea.html.

[11] Joongang Ilbo, Lee Young-jong, "North Korea Overseas Trade Reaps $1.97 Billion For Last Year," Seoul, 06/04/01, summarized in NAPSNet Daily Report, http://www.nautilus.org/napsnet/dr/0106/jun05.html. The figures come from the ROK's Korea Trade Investment Promotion Agency (KOTRA).

[12] Testimony by John Powell, Regional Director for Asia at the World Food Programme, before the Subcommittee on East Asia and the Pacific of the US House of Representatives International Relations Committee, May 2, 2002.

[13] Reuters, "Us To Donate 100,000 Tons Of Food To North Korea," Washington, 06/07/02.

[14] Korea Energy Economics Institute (KEEI, 1991), Yearbook of Energy Statistics, 1991. KEEI, Seoul, Republic of Korea.

[15] Hayes, P, (1993a), Cooperation on Environmental Issues with the DPRK. Nautilus Institute, Berkeley, California, USA. October 29, 1993.

[16] United Nations Food and Agriculture Organization (UNFAO) and World Food Programme (WFP, 1996), Special Alert No. 267, Democratic People's Republic of Korea.

[17] Government of the United States of America, "North Korea - Mild winter, dry spring could affect 2002/03 crops," April 10, 2002; JoongAng Ilbo, "North likely to face greater food shortages," April 4, 2002.

[18] Nikkei Shimbun, 5/19/97, "ROK VICE PRIME MINISTER UNDERSTANDS JAPAN'S CAREFUL STANCE ON FOOD AID TO DPRK". Page 8.

[19] "KEDO breaks ground for reactor Project in N. Korea", The Korea Herald, No. 13,639, August 20, 1997. Seoul, ROK. Page 1.

[20] Korean Peninsula Energy Development Organization (KEDO, 1996), Korean Peninsula Energy Development Organization, Annual Report, 1995. KEDO, Washington, D.C., July 31, 1996. "Appendix 1: HFO Deliveries" from Korean Peninsula Energy Development Organization (KEDO) Annual Report 2001, obtained from www.kedo.org, 5/31/2002.

[21] Von Hippel, D., and P. Hayes (1995), The Prospects for Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options. Nautilus Institute Report, Nautilus Institute for Security and Sustainable Development, Berkeley, California, USA. P. Hayes and D.F. Von Hippel (1997), "Engaging North Korea on Energy Efficiency". Chapter 9 in Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula, Young Whan Kihl and Peter Hayes, editors. M.E. Sharpe, Armonk, NY. Von Hippel, D.F., and P. Hayes (1996) "Engaging North Korea on Energy Efficiency". The Korean Journal of Defense Analysis, Volume VIII, No. 2, Winter 1996. Pages 177 - 221.

[22] Von Hippel, D. F., and P. Hayes (1995), The Prospects For Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options. Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. December, 1995. P. Hayes and D.F. Von Hippel (1997), "Engaging North Korea on Energy Efficiency". Chapter 9 in Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula, Young Whan Kihl and Peter Hayes, editors. M.E. Sharpe, Armonk, NY. Von Hippel, D.F., and P. Hayes (1996) "Engaging North Korea on Energy Efficiency". The Korean Journal of Defense Analysis, Volume VIII, No. 2, Winter 1996. Pages 177 - 221.

[23] V. Kalashnikov, personal communication, 9/97.
[24] Ross, M. and L. Feng (1990), "The Energy Efficiency of the Steel Industry of China". Energy. V. 16, No. 5, pp. 833-848, 1991.
[25] Document in authors' files [CE1].
[26] Document in authors' files [H1].
[27] Document in authors' files [HT1].
[28] Document in authors' files [HT1].
[29] The Economist Intelligence Unit (1994), South Korea, North Korea No. 1 1994. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.
[30] Trigubenko, M. (1991), "Industry of the DPRK". Paper presented at Korea Development Institute symposium, Seoul, ROK, October, 1991. Quoted in The Economist Intelligence Unit (1993?), China, North Korea Country Profile 1992-1993. The Economist Intelligence Unit, London, United Kingdom.
[31] Document from authors' files [HT1].
[32] Far Eastern Economic Review (1995). 1995 Asia Yearbook, North Korea.
[33] Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.
[34] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[35] The Economist Intelligence Unit (1994), South Korea, North Korea No. 1 1994. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.
[36] The Economist Intelligence Unit (1994), South Korea, North Korea No. 1 1994. The Economist Intelligence Unit, London, United Kingdom. Country Report, 1st Quarter 1994.
[37] Korea Foreign Trade Association (1993), Major Economic Indicators for North Korea.
[38] Gordon, D. (1991) Steering a New Course: Transportation, Energy and the Environment. Island Press, Washington, D.C., USA.
[39] Korea Foreign Trade Association (1993), Major Economic Indicators for North Korea.
[40] Federal Research Division, US Library of Congress (1993), North Korea, A Country Study. Edited by Andrea M. Savada. Research completed 1993. US Government Printing Office, Washington, DC, USA. Available (in part) on the World-wide web at http://lcweb2.loc.gov/frd/nktoc.html#nk0006.
[41] Professor Y.S. Jang, 1995, personal communication.
[42] Document in authors' files [HT1].
[43] Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), The Electric Future of Korea. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.
[44] Document from authors' files [FA].
[45] Document in authors' files [KJ1].
[46] Liu, F. (1993), Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350.
[47]Liu, F., W.B. Davis, and M.D. Levine (1992), An Overview of Energy Supply and Demand in China. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-32275 UC-350.
[48] Liu, F., W.B. Davis, and M.D. Levine (1992), An Overview of Energy Supply and Demand in China. Energy Analysis Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-32275 UC-350.
[49] Document in authors' files [KJ1].
[50] Document in authors' files [IF1].
[51] Liu, F. (1993), Energy and Conservation in China's Residential and Commercial Sectors: Patterns, Problems, and Prospects. Energy Analysis Program, Energy and Environmental Division, Lawrence Berkeley Laboratory, Berkeley, California, USA. LBL-33867 UC-350.
[52] US Defense Intelligence Agency (1990?), North Korea, The Foundations for Military Strength. US Defense Intelligence Agency, Washington, DC, USA.
[53] US Headquarters Department of the Army (1982), Opposing Force Training Module, North Korean Military Forces. Department of the Army, Washington, DC, USA. February, 1982. Field Manual No. 34-21.

[54] US Headquarters Department of the Army (1982), Opposing Force Training Module, North Korean Military Forces. Department of the Army, Washington, DC, USA. February, 1982. Field Manual No. 34-21.US Department of Defense (1994), North Korea Handbook. US Department of Defense, Washington, DC, USA.
[55] US Headquarters Department of the Army (1982), Opposing Force Training Module, North Korean Military Forces. Department of the Army, Washington, DC, USA. February, 1982. Field Manual No. 34-21.
[56] Jane's (1990/91, 1981/82, 1972/73, 1968/69), Jane's All the World's Aircraft. 1990/91, 1981/82, 1972/73, and 1968/69 editions. Jane's Publishing Co., N.Y., NY, USA.
[57] Chant, C., (1990), Air Forces of the World. Brian Trodd Publishing House, Ltd. Taylor, J.W.R., and G. Swanborough (1979), Military Aircraft of the World. Ian Allen Ltd., UK (1979).
[58] US Headquarters Department of the Army (1982), Opposing Force Training Module, North Korean Military Forces. Department of the Army, Washington, DC, USA. February, 1982. Field Manual No. 34-21.
[59] Chapman, L.B. (1942), The Marine Power Plant. McGraw-Hill, N.Y., N.Y., USA.
[60] Freedman, N. (1984), Submarine Design and Development. Naval Institute Press, Annapolis, MD, USA.
[61] Ross, M. and L. Feng (1990), "The Energy Efficiency of the Steel Industry of China". Energy. V. 16, No. 5, pp. 833-848, 1991.
[62] P. Zimmerman, personal communication, 1995.
[63] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[64] Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.
[65] Document in authors' files [HT1].
[66] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK). Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.
[67] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[68] Korea Foreign Trade Association (1993), Major Economic Indicators for North Korea.
[69] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[70] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[71] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[72] China Custom Statistics, 1996 (Information obtained via personal communication from Mr. David Fridley, Lawrence Berkeley National Laboratory).
[73] Korean Energy Economics Institute (KEEI, 1996). Personal communication from Mr. Dongseok ROH, Electricity Policy Division.
[74] Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.
[75] Fridley, D. (1996), Lawrence Berkeley National Laboratory (personal communication).
[76] Document in authors' files [HT1].
[77] Document in authors' files [TP1].
[78] Document in authors' files[T1].
[79] Document in authors' files [HT1].
[80] Document in authors’ files [EE1].
[81] Document in authors’ files/personal correspondence.
[82] Choi Su Young (1993), Study of the Present State of Energy Supply in North Korea, Research Institute for National Unification (RINU), Seoul, (ROK).
[83] ROK Ministry of Unification (1996), “Electric Generation Capacity and Actual Generation”. Obtained from World-wide web site http://www/unikorea.go.kr/eng/ja/table/enk21.htm.
[84] Moiseyev, V. (1996), The Electric Energy Sector of the DPRK Paper presented at the workshop on "Security on the Korean Peninsula," November 21, 1996, Diplomatic Academy, Moscow, sponsored by the Center for Nonproliferation Studies at the Monterey Institute of International Studies (with funding from the Rockerfeller Foundation).
[85] A. Karabanov (1993); personal communication.

[86] Document in authors' files [EE1].
[87] (Document in authors' files [EP1].
[88] Sinton, J., editor (1996), China Energy Databook 1996 Edition, Revised January 1996. Lawrence Berkeley National Laboratory, University of California, Berkeley, California, USA. LBL-32822.Rev.3. UC-900.
[89] UNDP (1994), Studies in Support of Tumen River Area Development Programme. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.
[90] Document in authors' files [EE1].
[91] Document in authors' files [EE1].
[92] Kim, E.-W., H. Kim, H.-K. Lim, C. Nahm, M.-C. Shin, and Y. Kim (1983), The Electric Future of Korea. Resource Systems Institute, Honolulu, Hawaii, USA. Research Materials RM-83-8.
[93] Moiseyev, V. (1996), The Electric Energy Sector of the DPRK Paper presented at the workshop on "Security on the Korean Peninsula," November 21, 1996, Diplomatic Academy, Moscow, sponsored by the Center for Nonproliferation Studies at the Monterey Institute of International Studies (with funding from the Rockefeller Foundation).
[94] Document in authors' files [EP1].
[95] UNDP (1994), Studies in Support of Tumen River Area Development Programme. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.
[96] Document in authors' files [EP1].
[97] UNDP (1994), Studies in Support of Tumen River Area Development Programme. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.
[98] UNDP (1994), Studies in Support of Tumen River Area Development Programme. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.
[99] Document in authors' files [EP1].
[100] Document in authors' files [EP1].
[101] Document in authors' files [EP1].
[102] Hayes, P. (1997), "Supply of Light-Water Reactors to the DPRK". Chapter 3 in Peace and Security in Northeast Asia: The Nuclear Issue and the Korean Peninsula, Young Whan Kihl and Peter Hayes, Editors. M.E. Sharpe, Armonk, New York, USA.
[103] UNDP (1994), Studies in Support of Tumen River Area Development Programme. Prepared by KIEP, Seoul, ROK for the UNDP, July, 1994.
[104] International Petroleum Encyclopedia, 1996. Tulsa, Oklahoma Petroleum Publishing Company, Tulsa, OK.
[105] Fridley, D. (1996), Lawrence Berkeley National Laboratory (personal communication).
[106] Fridley, D. (1996), Lawrence Berkeley National Laboratory (personal communication).
[107] International Petroleum Encyclopedia, 1996. Tulsa, Oklahoma Petroleum Publishing Company, Tulsa, OK.
[108] Shen, W.B. (1988), "Progress of Energy Saving in China's Petrochemical Industry". In Meyers, S. (Ed.), Proceedings of the Chinese - American Symposium on Energy Markets and the Future of Energy Demand, Nanjing, China June 22-24, 1988. Lawrence Berkeley Laboratory, Berkeley, California, USA.
[109] Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.
[110] Document in authors' files [H2-A2].
[111] Chinese language spreadsheet dated 12-Feb-93 provided by J. Sinton of Lawrence Berkeley Laboratory; Sinton, J. (1995), "Physical Intensity of Selected Industrial Products". Spreadsheet printout. LBL" Lawrence Berkeley Laboratory, Berkeley, California, USA.
[112] Document in authors' files [R1].
[113] "Energy 'Crisis' Threatens Economy", Pukhan (Seoul, ROK) March 1993, pages 39-45, by Naeoe Tongsin reporter Kim Sang-hwan.
[114] Document in authors' files [T1].
[115] Jang, Young Sik (1994), North Korean Energy Economics. Korea Development Institute.
[116] Chandler, W. U., Z. Dadi and J. Hamburger (1993), U.S .- China Cooperation for Global Environmental Protection. Pacific Northwest Laboratory, Richmond, Washington, USA. Chandler, W. U. (1993), AISU's China Program Update June 1993. Battelle, Pacific Northwest Laboratory, Richmond, Washington, USA.
[117] Sathaye, J., R. Friedmann, S. Meyers, O. de Buen, A. Gadgil, E. Vargas, and R. Saucedo (1994), "Economic Analysis of Ilumex: A Project to Promote Energy-Efficient Residential Lighting in Mexico". Energy Policy, February, 1994, pp. 163 - 171.

[118] Martinot, E. (1994), Technology Transfer and Cooperation for Sustainable Energy Development in Russia: Prospects and Case Studies of Energy Efficiency and Renewable Energy. Energy and Resources Group, University of California at Berkeley, Berkeley, California, USA. [Summary of a Ph.D. Dissertation - Draft]
[119] Von Hippel, D. F., and P. Hayes (1995), The Prospects For Energy Efficiency Improvements in the Democratic People's Republic of Korea: Evaluating and Exploring the Options. Nautilus Institute for Security and Sustainable Development, Berkeley, CA, USA. December, 1995.